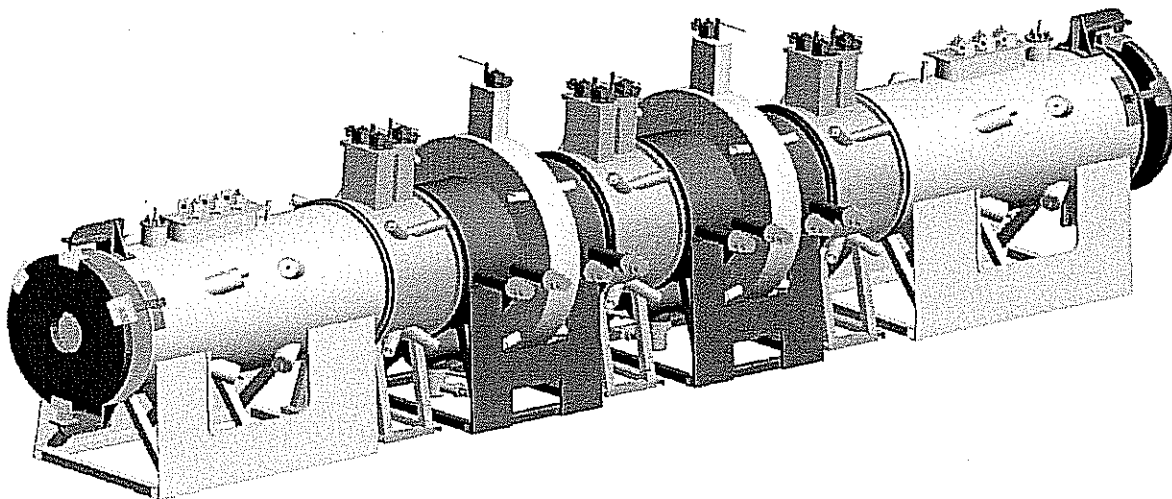# LAWRENCE BERKELEY NATIONAL LABORATORY

FINAL ENGINEERING DESIGN FOR MICE SPECTROMETER SOLENOID MAGNETS
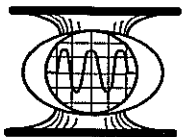## *LBL P. O. 6806258*

SUBMITTED BY : WANG NMR. INC.
550 NORTH CANYONS PARKWAY
LIVERMORE, CA. 94551
DATE : September 6, 2006

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Wang NMR, Inc.

550 North Canyons Parkway , Livermore, Ca. 94551

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CHAPTER I

INTRODUCTION TO MICE SOLENOID COIL SYSTEM

The purpose of the MICE spectrometer solenoid is to provide a uniform field for a scintillating fiber tracker, and thus, it is also called tracker solenoid. The uniform field is produced by a long center coil and two short end coils. Together, they produce 4T field with a uniformity of better than 1% over a detector region 1000 mm long and 300 mm in diameter. Throughout most of the detector region, the field uniformity is better than 0.3%.

In addition to the uniform field coils, we have match coil 1 and match coil 2. These two coils can be independently adjusted to match uniform field region to the focusing coil field. Figure I-1 shows the tracker solenoid cold mass design. Figure I-2 shows the cold mass support against 50 ton axial load. Figure I-3 shows the cryogen free system with cryocooler, recondenser, and Hi-Tc lead. Figure I-4 shows the vacuum vessel. Finally, Table I-1 shows the list of magnet parameters Drwg MICE- 0000 shows the final design of overall cross section if cryocooler installed in the sleeve. Drwg MICE-0000A shows the overall cross section if cryocooler is directly bolted to cold mass.

Table I-1   Tracker Magnet Parameters

Parameter	Coil package length = 2544 mm				
	Match 1	Match 2	End 1	Center	End 2
Coil length (mm)	201.2	199.5	110.6	1314.3	110.6
Coil inner radius (mm)	258	258	258	258	258
Coil thickness (mm)	44.7	29.8	59.6	21.3	63.9
Number of layers	42	28	56	20	60
Number of turns per layer	120	119	66	784	66
Coil overall current density (A mm^{-2})	120.06	141.13	139.84	149.04	148.64
Coil current I (A)	214.2	251.8	248.9	265.3	265.3
Coil self inductance (H)	17.47	9.59	15.39	51.72	16.87
Coil Stored Energy at I (MJ)	0.4	0.3	0.48	1.83	0.59

Separately Powered   Uniform Field Magnet S

* The uniform field magnet coils in series have a self inductance of 78 H.

Fig I-1 Tracker Solenoid Cold Mass

Coil Cover

End Coil 2

End Coil 1

Match Coil 1

724

2544

490

Center Coil

Liquid Helium

Match Coil 2

Coil Spacer
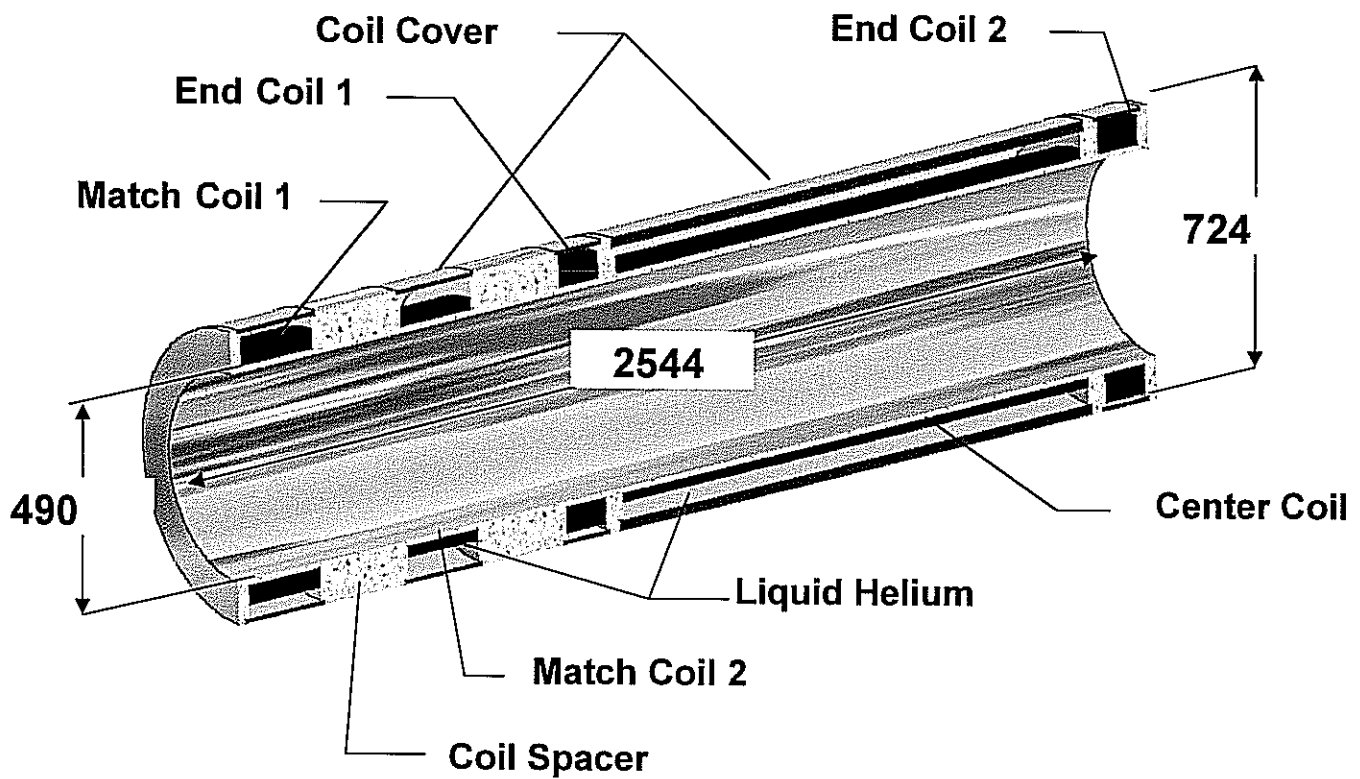
The two end coils and the center coil
form the spectrometer magnet, which
has a field good to 0.3 % in a region
300 mm in diameter and 1000 mm long.

Fig I-2 Tracker Solenoid 50 Ton Longitudinal Force Cold Mass Support System

300 K Support End

Cold Mass Assembly

60 K Support Intercept

Support Band

4 K Support End
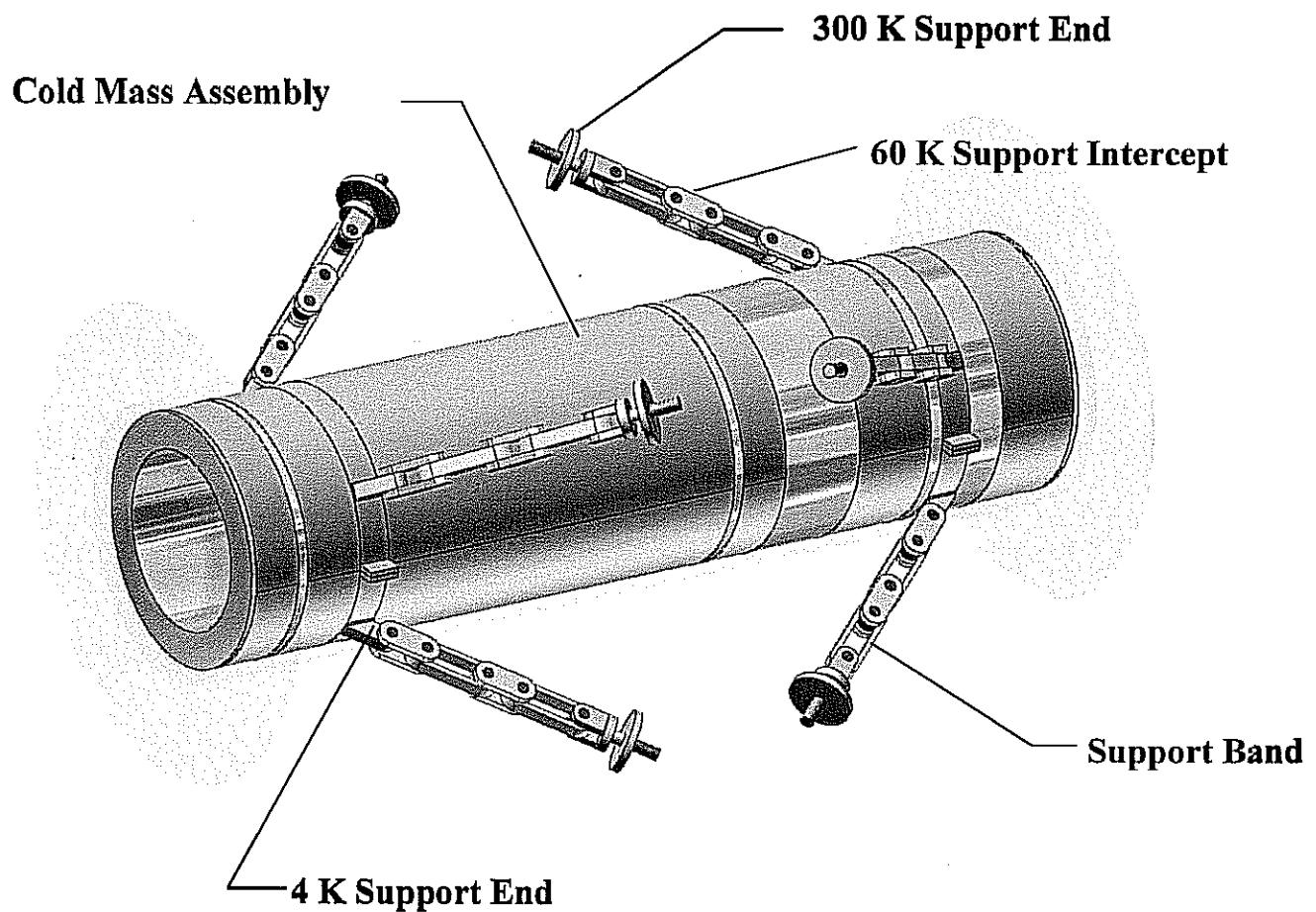
Fig I-3   Tracker Magnet Cold Mass, Coolers
Cryogenic Distribution System

Magnet Leads

Magnet Cooler

Condenser Box

Cold Mass Support

Cold Mass Assembly

Liquid Helium Pipe

Helium Gas Pipe
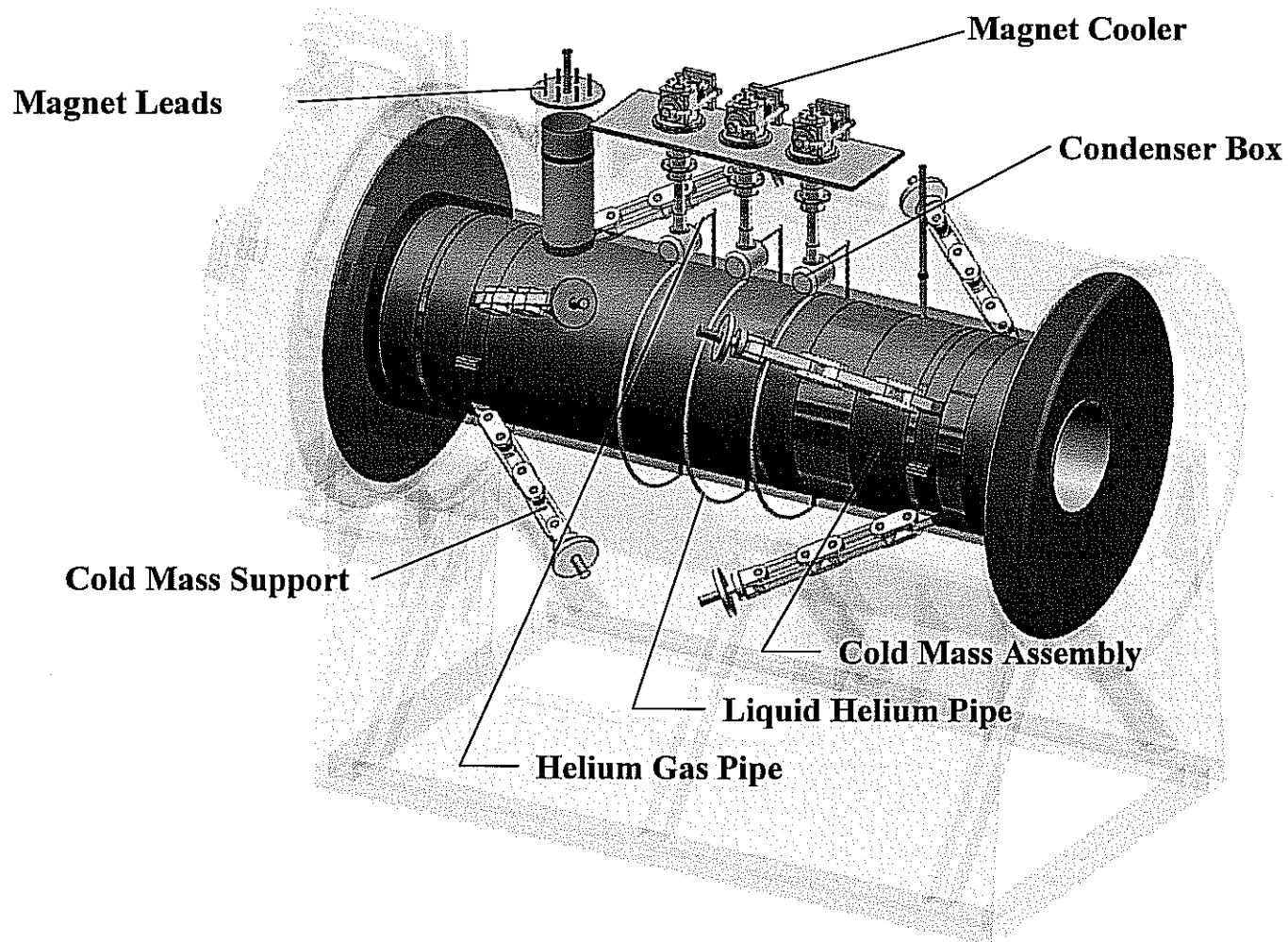
Fig I-4
Tracker Magnet Vacuum Vessel and Iron Shield

Cooler Neck

He Fill Neck

Lead Neck

Cold Mass Support

PMT Iron Shield

Space for Radiation Shield

Magnet Stand

He CONDENSER

1/4" VCR

LHe

He
GAS

SUSPENSION STRIP

LHe VESSEL

COIL

CRYOCOOLER CHPT415

CHARGING LEADS

INNER BORE

404 I.D. ++404 O.D.

120

1/4" VCR

2544

2923

SERVICE TOWER

2735

50K SHIELD

VACUUM VESSEL

He CONDENSER

1143 DIA.

1514 DIA.

NOTES:
1) DIMENSIONS ARE IN mm

UNLESS OTHERWISE
SPECIFIED
TOLERANCES
.XX ± .005
.XX ± .02

He CONDENSER

1/4" VCR

LHe

He GAS

SUSPENSION STRIP

LHe VESSEL

COIL

CRYOCOOLER CHPT415

CHARGING LEADS

+404 O.D.

404 I.D.

INNER BORE

1/4" VCR

2735

SERVICE TOWER

2544

2923

50K SHIELD

VACUUM VESSEL

He CONDENCER

1143 DIA.

1514 DIA.

120

NOTES:
1) DIMENSIONS ARE IN mm

CHAPTER II

MICE Detector Spectrometer Solenoid Coil Assembly Design

Engineering design drawing for coil assembly is shown in Appendix II-1

II-1. Five Coil Design, on-axis Field Profile and Peak Field on Conductor

The solenoid consists of five coils; match coil 1 (M1), match coil 2 (M2), the end coil 1 (E1), the center coil (C), and the end coil 2 (E2). The end coil 1, the center coil, and the end coil 2 are connected in series and form the spectrometer solenoid. The end coil 1 and the end coil 2 can be fine-tuned and adjusted to ensure spectrometer solenoid field uniformity of 1% over detector volume of 300 mm diameter by 1000 mm long. On the other hand, match coil 1 and match coil 2 are each an independently-adjustable coil. These match coils will be tuned to match muon beam between spectrometer coil set and the focusing coil set.

The magnet design is shown in Table II-1-1.

The central field profile is shown in Figure II-1-1. The peak field on conductor in each coil is shown in Table II-1-1 and Fig II-1-2.

Table II-1-1   MICE MAGNET DESIGN

PARAMETER	MATCH1	MATCH2	END1	CENTER	END2
LBL ORIGINAL SPEC.					
R1 (MM)	258	258	258	258	258
COIL THICKNESS (MM)	46.2	30.8	61.6	22	68.2
R2 (MM)	304.2	288.8	319.6	280	326.2
MID-Z POSITION	124	564	964	1714	2464
COIL LENGTH (MM)	198	197	110	1294	110
Z1(MM)	25	465.5	909	1067	2409
Z2(MM)	223	662.5	1019	2361	2519
# OF LAYER	42	28	56	20	62
# OF TURN PER LAYER	120	119	66	784	66
WANG NMR DESIGN: (MM)					
CONDUCTOR INSUL THK	1.0000	1.0000	1.0000	1.0000	1.0000
CONDUCTOR INSUL WIDTH	1.6500	1.6500	1.6500	1.6500	1.6500
LAYER THICK(+2.5 MIL)	1.0643	1.0643	1.0643	1.0643	1.0643
TURN WIDTH (+ 1 MIL)	1.6764	1.6764	1.6764	1.6764	1.6764
SP	56.0499	56.0499	56.0499	56.0499	56.0499
DESIGN CURRENT	214.2	251.8	249.5	265.9	265.2
COIL THICK NESS	44.699	29.799	59.599	21.285	65.984
COIL LENGTH	201.168	199.492	110.642	1314.298	110.642
B PEAK (T)	4.43	4.01	5.90	4.19	6.37
MID R POSITION (LBL)	281.10	273.40	288.80	269.00	292.10
MID R POSITION (Wang)	280.35	272.90	287.80	268.64	290.99
Delta Mid-R (mm)	0.75	0.50	1.00	0.36	1.11
DESIGN COIL DIMENSION (MM)					
R1(MM)	258.000	258.000	258.000	258.000	258.000
R2	302.699	287.799	317.599	279.285	323.984
Z1	23.416	464.254	908.679	1056.851	2408.679
Z2	224.584	663.746	1019.321	2371.149	2519.321
SIDE WALL INSULATION (.125" G-10 + KAPTON)				3.2 MM	
COIL MANDREL INSULATION				1.0 MM	
(2 LAYERS G-10 0.015" + 2 LAYERS KAPTON 0.005")					
BOBBIN DESIGN:					
R1(MM)	257	257	257	257	257
R2					
Z1	20.22	461.05	905.48	1053.65	2405.48
Z2	227.78	666.95	1022.52	2374.35	2522.52
COIL BOBBIN DESIGN IN INCH					
R1(INCH)	10.118	10.118	10.118	10.118	10.118
R2					
Z1	0.796	18.152	35.649	41.482	94.704
Z2	8.968	26.258	40.257	93.478	99.312

Fig II-1-1

Magnetic Induction on Axis versus the Axial Position in the Solenoid

MICE (TRACKER MAGNET)FIELD PLOT - Position along the OVERALL FIELD AXIS (CM) IN THE WARM BORE AREA
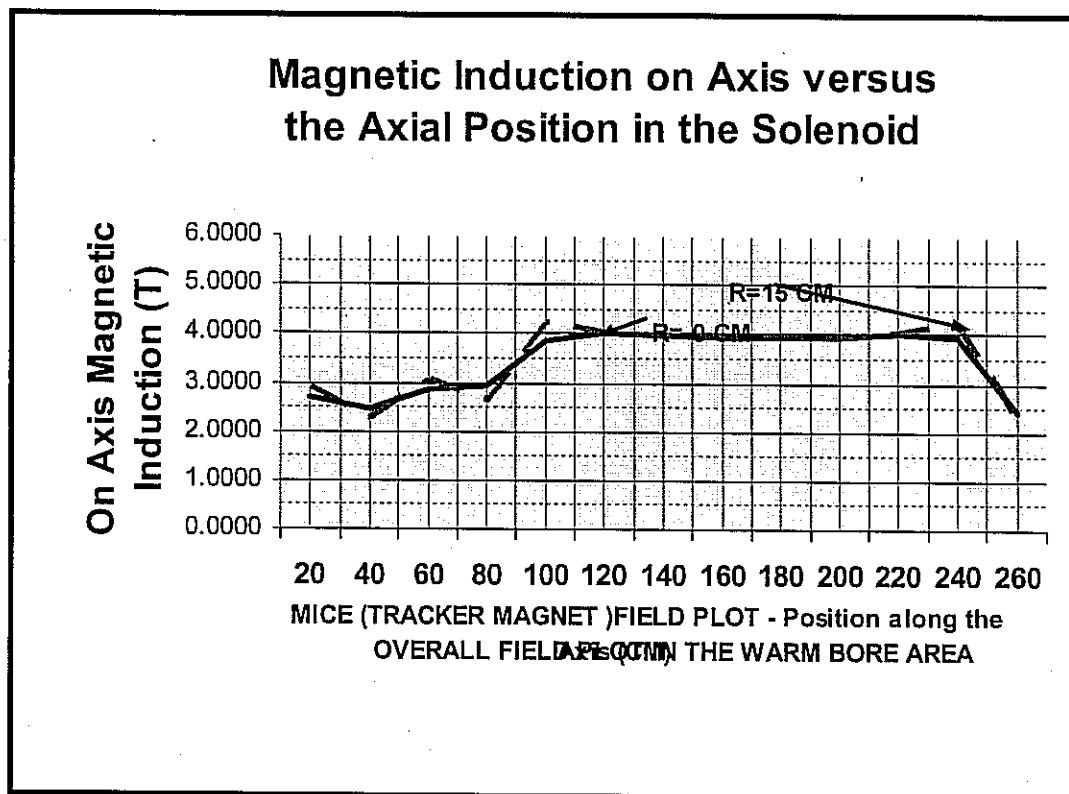
Fig II-1-2

Tracker Solenoid Peak Field
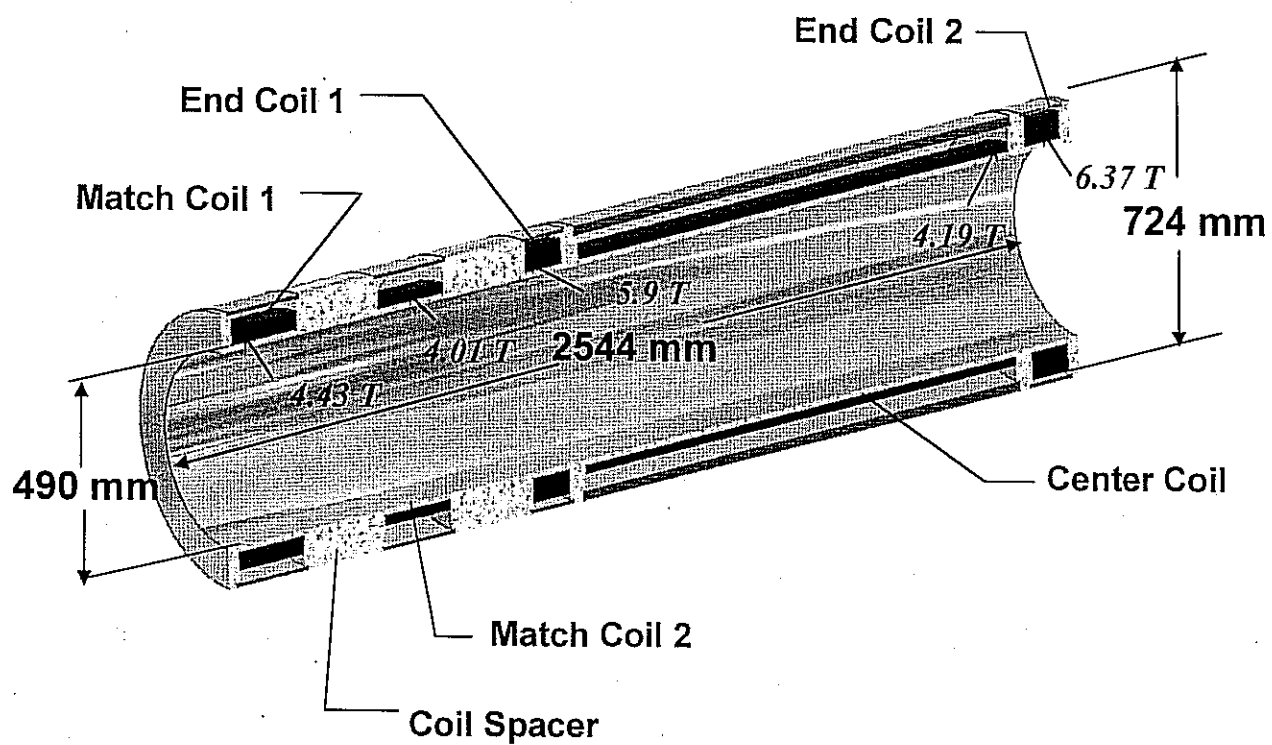
II-2. Conductor Design, Ic-Bc, Operating Current and Load Line (LBL task)

(A) <u>Conductor Design</u>

LBL has designed and procured a rectangular conductor with formvar insulation (dimension: 1.0 mm by 1.65 mm). Its copper to superconductor ratio is 3.9±0.4. The number of filaments is 222. The filament diameter is 41 μ. The filament twist pitch is 19±3 mm. The conductor crossection is shown in Figure II-2-1. Six spools of MICE conductors were delivered to LBNL in May 2006. The QC on the mechanical properties are shown in Table II-2-1. It will be delivered to Wang NMR Inc. in July 2006.

(B) <u>Ic-Bc</u>

The Ic-Bc electrical specification of the superconductor is > 760A at 4.2K and 5T. The QC test on each spool is shown in Table II-2-2. A typical short sample test is shown in Figure II-2-2, which is further plotted in Figure II-2-3.

(C) <u>Operating Current, Load Line, and Temperature Margin</u>

As shown in Figure II-2-3, the load lines for each of five coils in spectrometer solenoid are shown to have temperature margin of more than 2K.

Fig II-2-1   Conductor Cross-section

1.65 mm

1.00 mm

RRR = 70 Copper   Hem Kanithi, OKAS, Waterbury, CT 06410   41 μm Nb-Ti Filament
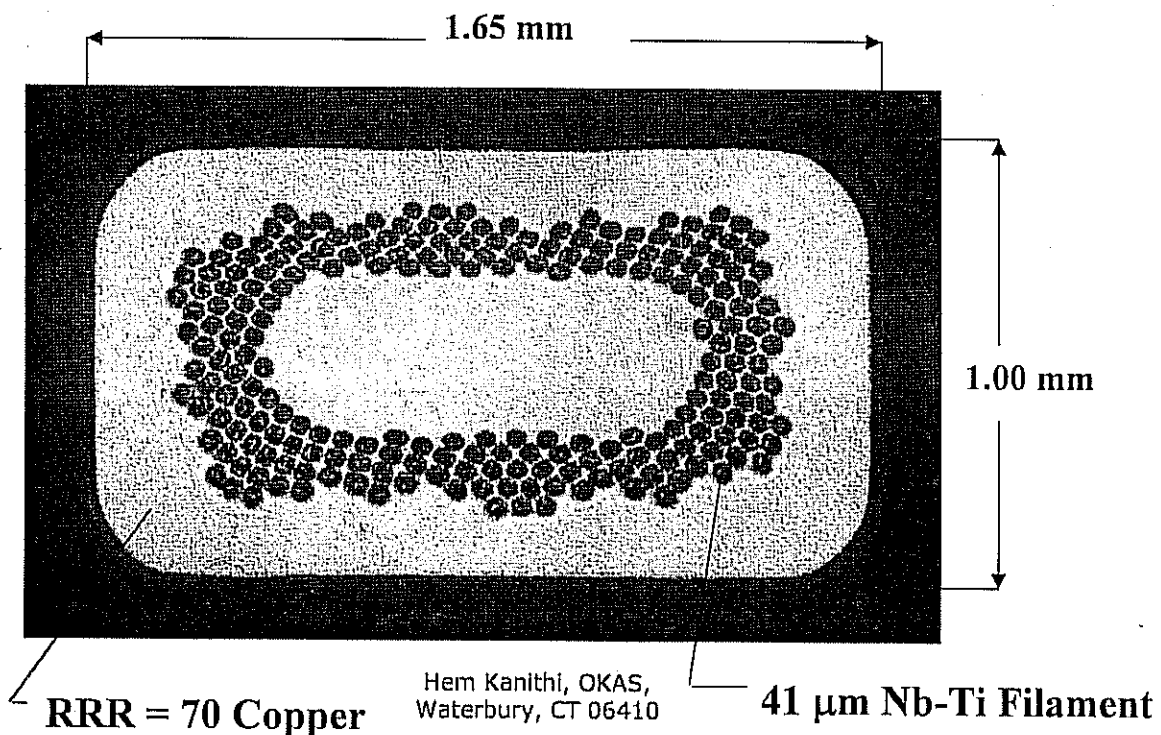
Table II-2-1
Conductor Mechanical Characteristics

Both tests look for filament breakup
and defects in the filament bundle.

Piece ID	Length, meters	Weight, kgs	Insul Thk	Insul Width	Bend test	Eddy current
Spec			0.97-1.00	1.62-1.65	pass	Pass
36680	32964	393.7	0.995	1.644	pass	pass
36679	33140	396.5	0.996	1.645	pass	pass
36761-1	27363	329	0.994	1.646	pass	pass
36761-2	5366	64.7	0.994	1.646	pass	pass
36760-1-1	15218	182.2	0.994	1.644	pass	pass
36760-1-2	7440	89.2	0.994	1.645	pass	pass
Total	121491	1455				

Hem Kanithi, OKAS,
Waterbury, CT 06410

The dimensions are acceptable.

Table II- 2-2
Conductor Electrical Characteristics

Piece ID	End A			End B			Billet RRR
	Cu/Sc	Ic(5T)	n(5T)	Cu/Sc	Ic(5T)	n(5T)	
Spec.	3.5-4.3	>760	>35	3.5-4.3	>760	>35	~80
36680	3.90	826	50	3.74	955	57	75
36679	3.55	868	54	3.70	826	51	71
36761-1	3.65	867	49	3.83	872	49	91
36761-2	3.83	872	49	3.83	826	51	91
36760-1-1	3.84	793	56	3.71	824	57	73
36760-1-2	3.71	824	57	3.72	837	60	73

Hem Kanithi, OKAS,
Waterbury, CT 06410

The specified conductor critical current is >760 @ 4.2 K and 5 T.
The specified conductor n value is >35.
The specified conductor copper to S/C ratio is 3.9 ± 0.4.
The RRR values for the conductor copper are acceptable.

Fig II- 2-2

Typical OKAS Short Sample Test Plot
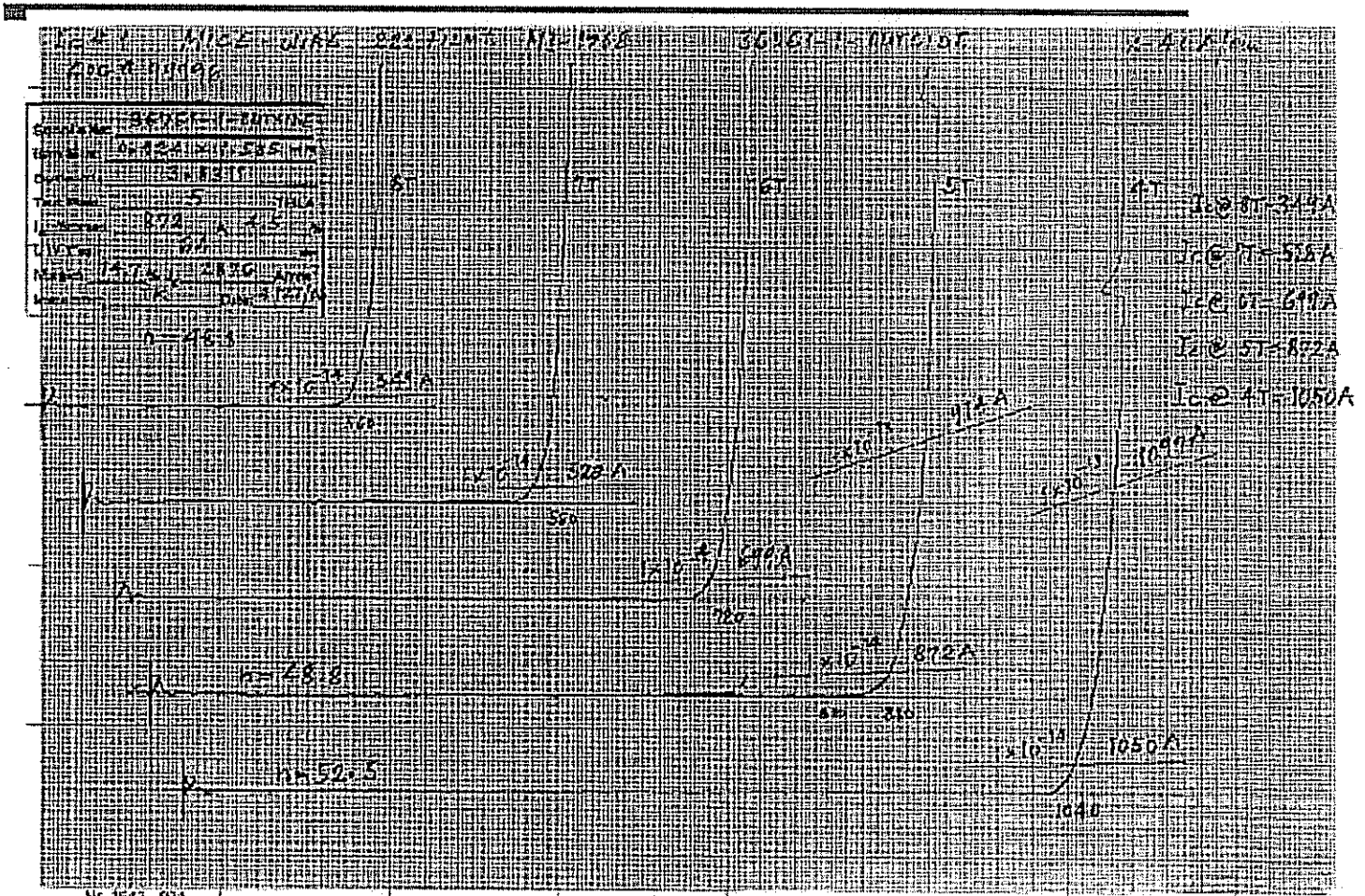
Hem Kanithi, OKAS,
Waterbury, CT 06410

Fig II- 2-3

Design Tracker Magnet Load Lines and Ic Versus B
for OKAS Superconductor

OKAS Conductor (760 A @ 5 T)
1.65 mm X 1.00 mm (insulated)
~222 NbTi ifilaments, 41 microns dia.
Twist Pitch = 19 +/- 3 mm
Cu/Sc = 3.55~3.90 : 1
RRR=71 to 91

Ic Vs B
OKAS Conductor

Load lineCenter
(265.9 A @ 4.19T)

Load line End 2
(265A at 6.37 T)

Load line Match 2
(251 A @ 4.01 T)

Load line Match 1
(214.2 A @ 4.43T)

Load line End 1
(249.5A @ 5.9T)

Current (A)

900
800
700
600
500
400
300
200
100
0

Magnetic Induction (T)

0 1 2 3 4 5 6 7 8 9

II-3 Insulation Design of Conductor, Turn-to-Turn, Layer-to-Layer, and of Coil to Ground

(A) Conductor insulation

The superconducting composite shall be insulated with formvar (0.001" or 0.025 mm thick) per NEMA standard MW-1000 section 18-C poly-vinyl formal resin/ class 10J/ heavy build. The insulated overall dimension of conductor is 1.00 mm by 1.65 mm, with corner radii in the range of 0.2 mm to 0.475 mm.

(B) Turn-to-Turn Insulation

The turn-to-turn insulation including gap will be 0.050 mm (0.002") thick formvar.

(C) Layer-to-Layer insulation

The layer-to-layer insulation will be 0.0625 mm (2.5 mil) thick fiberglass cloth (E glass) plus 0.050 mm (0.002") formvar.

(D) Coil-to-ground insulation

Coil to mandrel will be insulated with 2 layers of Kapton (0.002" x 2) and two layers of G-10 sheets (0.018" x 2). Coil to the coil former side wall will be insulated with 0.125" G-10 and 0.002" Kapton.

These insulation design will be meggered test to satisfy 5 kV and 200 µA leakage current requirement.

II-4. Coil Winding Pack Design and Design of Coil Former

(A) Control winding density

During each layer winding, winding density (# of turn per cm) will be controlled to assure field uniformity.

(B) Coil layer and potting epoxy

2.5 mil thick fiberglass will be used for layer to layer winding. Stycast 2850 FT will be used to wet wind each coil layer.

(C) Aluminum Coil Banding to Support Coil Force

Outer most coil layer will be insulated with one layer kapton and two layers G-10 totaling 1 mm thick. A high strength aluminum alloy 6061T6 banding will be used to

band each coil. This will provide additional hoop force support and will ensure coil is tightly packed when it is cool-down.

(D) <u>Conductor Joints and Voltage Tap</u>

After banding, conductor joints will be made by lapping joints over at least 24" long. All joints will be carefully insulated, supported, and epoxy potted in a G-10 supporting plate. Heating due to conductor joints must be as small as possible to keep overall refrigerator load within cryocooler capability. If necessary, superconducting joints will be made to eliminate the heating due to joints. Voltage taps will be made at each joints.

(E) <u>Coil leading superconductors</u>

In the helium space, each coil leading conductors (in and out) will be soldered with at least three times superconductor/ copper to avoid burn out due to vapor locking. In the vacuum space, each coil leading conductors will be soldered with at least five time superconductor/ copper to avoid burn out. The leading conductor lengths should be kept as short as possible. All leading conductor must be well-insulated and well-supported.

(F) <u>The inner coil radius (R1)</u>

The inner coil radius of all coils will be 258 mm or 10.158" (R1).

(G) <u>The turn-to-turn width</u>

Adding a turn-to-turn gap of 0.001" to conductor width 1.65 mm (0.065"), the design turn-to-turn width will be 0.001" + 0.065" = 0.066".

(H) <u>The layer-to- layer thickness</u>

The layer-to-layer insulation will be 0.0025" fiberglass cloth, thus layer-to-layer thick will be 0.0025"+0.0394" = 0.0419".

The winding build ($\Delta R \times \Delta Z$), the number of layer, L, and the number of turns per layer, N are shown in Table II-4-1.

Table II-4-1 COIL DESIGN PARAMETERS

COIL	MATCH 1	MATCH 2	END 1	CENTER	END 2
# of layer (L)	42	28	56	20	62
# of turns/ layer (N)	120	119	66	784	66
Radial Coil Build (ΔR)	1.7598"	1.1732"	2.3464"	0.838"	2.5978"
Axial Coil Build (ΔZ)	7.92"	7.854"	4.356"	51.744"	4.356"
Inner Coil Radius (R1)*	10.158"	10.158"	10.158"	10.158"	10.158"
Outer Coil Radius (R2)*	11.917"	11.331"	12.504"	10.996"	12.755"
Mean Coil R* (mm) (Current Center)	280.35 mm	272.9 mm	287.8 mm	268.65 mm	290.94 mm
Mean Coil Z** (mm) (Axial Current Center)	124±1	564±1	964±1	1714±1	2464±1
Coil Inner Z1** (mm) (inch)	23.4 (0.921")	464.25 (18.278")	908.7 (35.776")	1056.85 (41.608")	2408.7 (94.831")
Coil Outer Z2** (mm) (inch)	224.6 (8.843")	663.75 (26.132")	1019.3 (40.130")	2371.15 (93.352")	2519.3 (99.185")

* Radial dimensions are measured from the magnetic axis.
** Axial dimensions are measured from cold mass cryostat end of match coil 1.

(I) <u>Coil winding structure, coil former design, and coil axial groove width design</u>

As shown in Figure I-1 and Table I-1, the coil former will have an inner radius of 245 mm (9.646") and an overall coil former length (cold mass length) of 2544 mm (100.157"). Since all five coils shall have a G-10 sidewall thickness of 0.125", the longitudinal (axial) distance of each coil winding pack is calculated as shown in Table II-4-1.

(J) <u>Coil radial groove depth design</u>

As shown in Table II-4-1, each coil shall have enough radial groove depth to allow for: (i) coil to mandrel insulation 0.040", (ii) coil radial build, (iii) banding and its insulation (0.250"), and (iv) 0.75" space reserved for precool line, or intercoil connection. In addition, the center coil has the thinnest build, we plan to install coil protection system (2.5" radial build) on the surface of center coil banding, as shown in Figure II-4-1. Thus, the outer radius of each winding groove will be 11.25" + 2.5" = 13.75" R. The coil former design is shown in drawing MICE-C001.

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II-5. Calculation of the Axial Forces and Axial Magnetic Pressure

Radial field component, Br, generate axial magnetic force and pressure. Figure II-5-1 tabulates the total axial forces and maximum axial magnetic pressure for each coil.

Figure II-5-1. Axial Coil Force & Maximum Axial Pressure
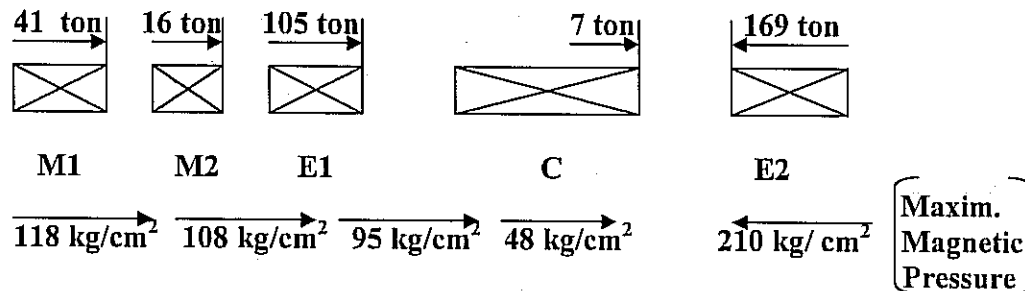
Therefore, E2 coil has maximum axial magnetic pressure of 210 kg/ cm^2.

II-6. Finite Element Stress Analyses for Coil and Reinforcement Rings

The coil forces consists of hoop forces and axial compressive forces. To set up finite element analyses and to compute hoop force and axial forces, we have computed the magnetic field component Bz and Br within the winding. The coil is divided into 25 axial-symmetric elements. The reinforcing cylinder is divided into 90 solid elements. Detail of finite element stress analyses are shown in Appendix II-6-1. The conductor stress in each coil is shown in Table II-6-1.
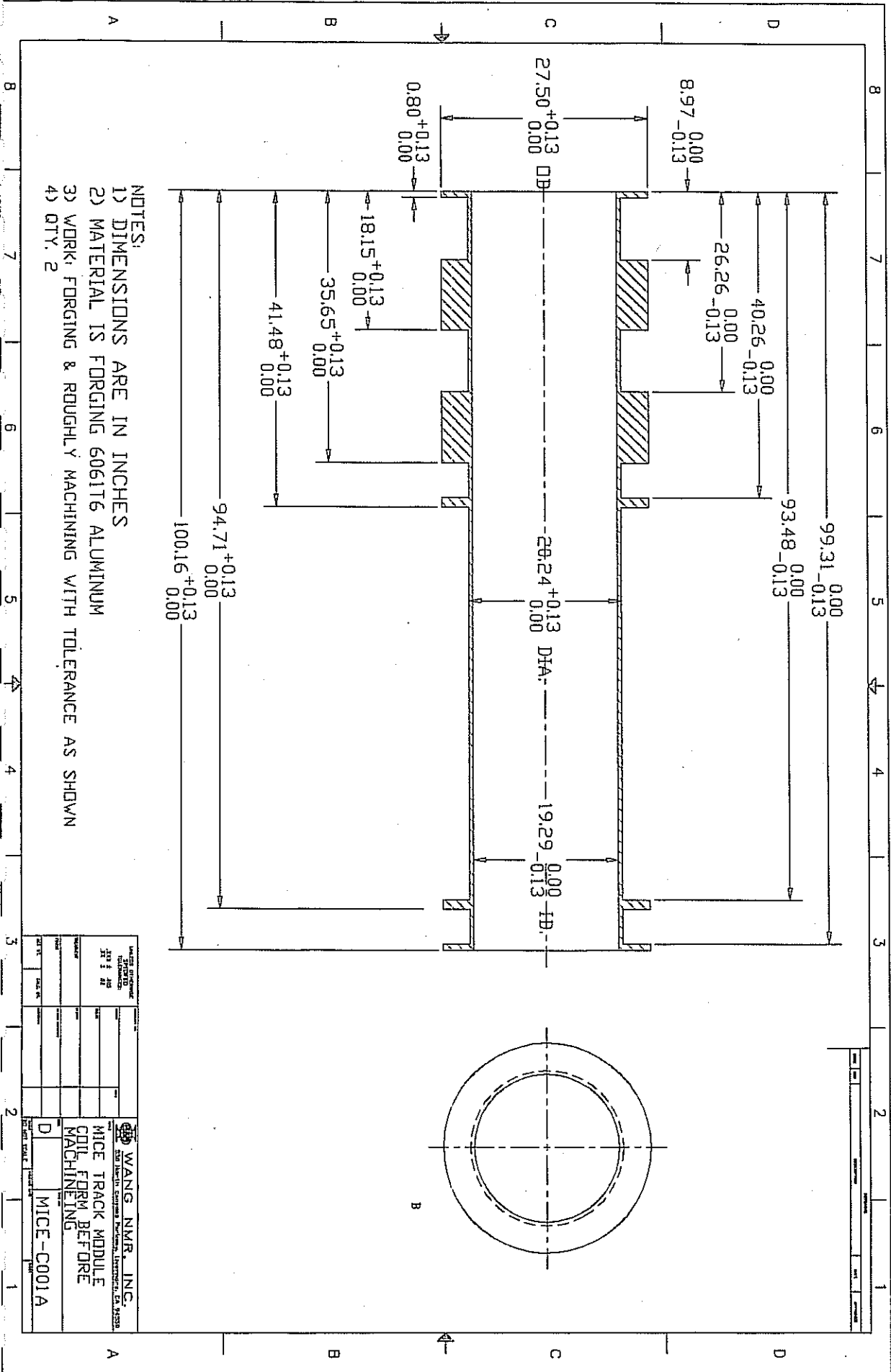
Table II-6-1 MAXIMUM COIL STRESS

	coil	hoop stress (kg/ cm^2)	compress stress (kg/ cm^2)
M$_1$	match 1	538.8	-182.5
M$_2$	match 2	643.3	-124.7
E$_1$	end 1	834.7	-298.2
C	center	818.2	-39.6
E$_2$	end 2	882.7	208.9

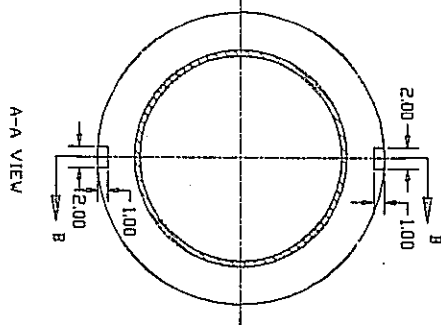The Von Mise Stress of Reinforce ring is 960.6 kg / cm^2

II-7. Coil Former Fabrication and Quality Control

Coil former is made of forging 6061T6 aluminum. After forging, besides chemical composition analyses and heat treatment certification, it must be inspected for dimensional tolerance and for surface finish, deburring, and for cleaniness. Then, it will be leak check for a sensitivity of better than 1 x 10^{-10} torr-liter/ sec.
The before-machined drawing is shown in Drwg MICE-C001A. The final machined former is shown in Drwg MICE-C001

8.97 +0.00 −0.13

27.50 +0.13 0.00 DIA.

0.80 +0.13 0.00

18.15 +0.13 0.00

26.26 +0.00 −0.13

40.26 +0.00 −0.13

35.65 +0.13 0.00

41.48 +0.13 0.00

99.31 +0.00 −0.13

93.48 +0.00 −0.13

28.24 +0.13 0.00 DIA.

19.29 +0.00 −0.13 ID.

94.71 +0.13 0.00

100.16 +0.13 0.00

NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS FORGING 6061T6 ALUMINUM
3) WORK: FORGING & ROUGHLY MACHINING WITH TOLERANCE AS SHOWN
4) QTY. 2

WANG NMR, INC.
550 North Canyon Parkway, Livermore, CA 94550

MICE TRACK MODULE
COIL FORM BEFORE MACHINEING

D   MICE-C001A
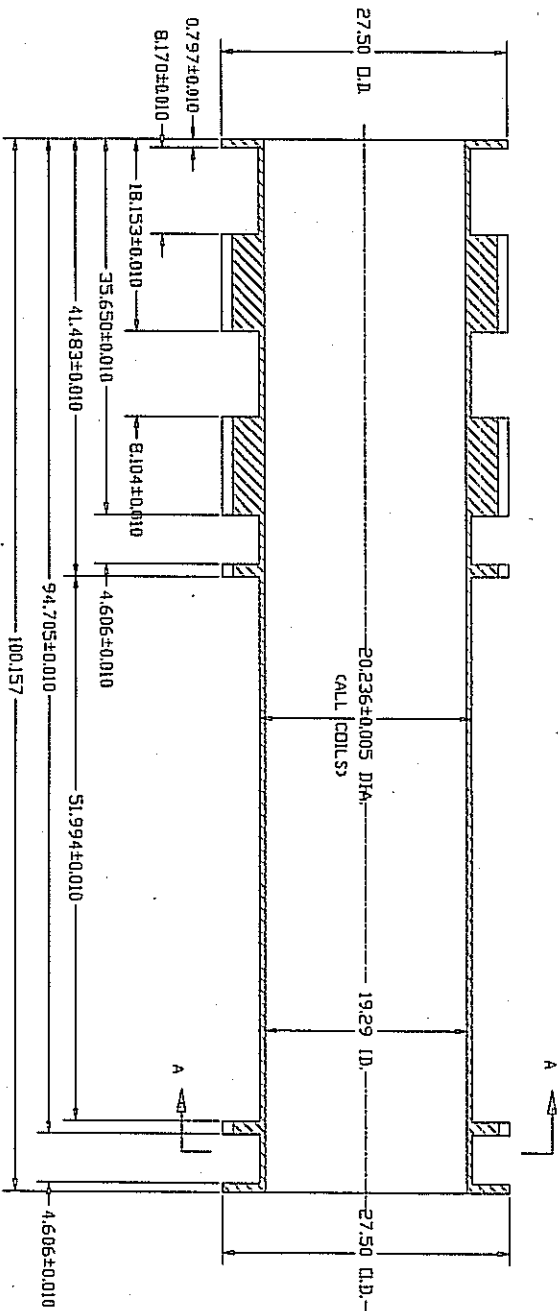
27.50 O.D.

0.797±0.010

8.170±0.010

18.153±0.010

35.650±0.010

41.483±0.010

8.104±0.010

94.705±0.010

4.606±0.010

51.994±0.010

100.157

20.236±0.005 DIA.
CALL (COILS)

19.29 I.D.

A

A

27.50 O.D.

4.606±0.010

B-B SECTION

NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS FORGING 6061T6 ALUMINUM
3) QTY. 2

A-A VIEW

2.00

2.00

1.00

1.00

B

B

WANG NMR, INC.
550 North Oakland Parkway, Livermore, CA 91550

MICE TRACK MODULE
COIL FORM

D

MICE-C001

II-8. Coil Former Insulation Installation and Ground-Plane Hi-Pot Testing

As shown in Drwg MICE-C002, the side wall of the coil former will be insulated with 0.125" G-10 plus 2 layers of kapton (0.002" thick) and one layer of artificial reconstituted mica (0.003") as slip plane. The hub of coil former will be insulated with 0.015" thick G-10 plus two layers of kapton as ground plane insulation and one layer of mica as slip plane.

Coil former insulation will be meggered to 5 kV.

II-9. Coil Winding Instruction and Short Checking For Turn-to-Turn and Layer-to-Layer

(A) Planned use of superconductor is shown in Fig II-9-1

Since conductor joint will generate significant heating to 4.2K, it is important to minimize the number of joints.
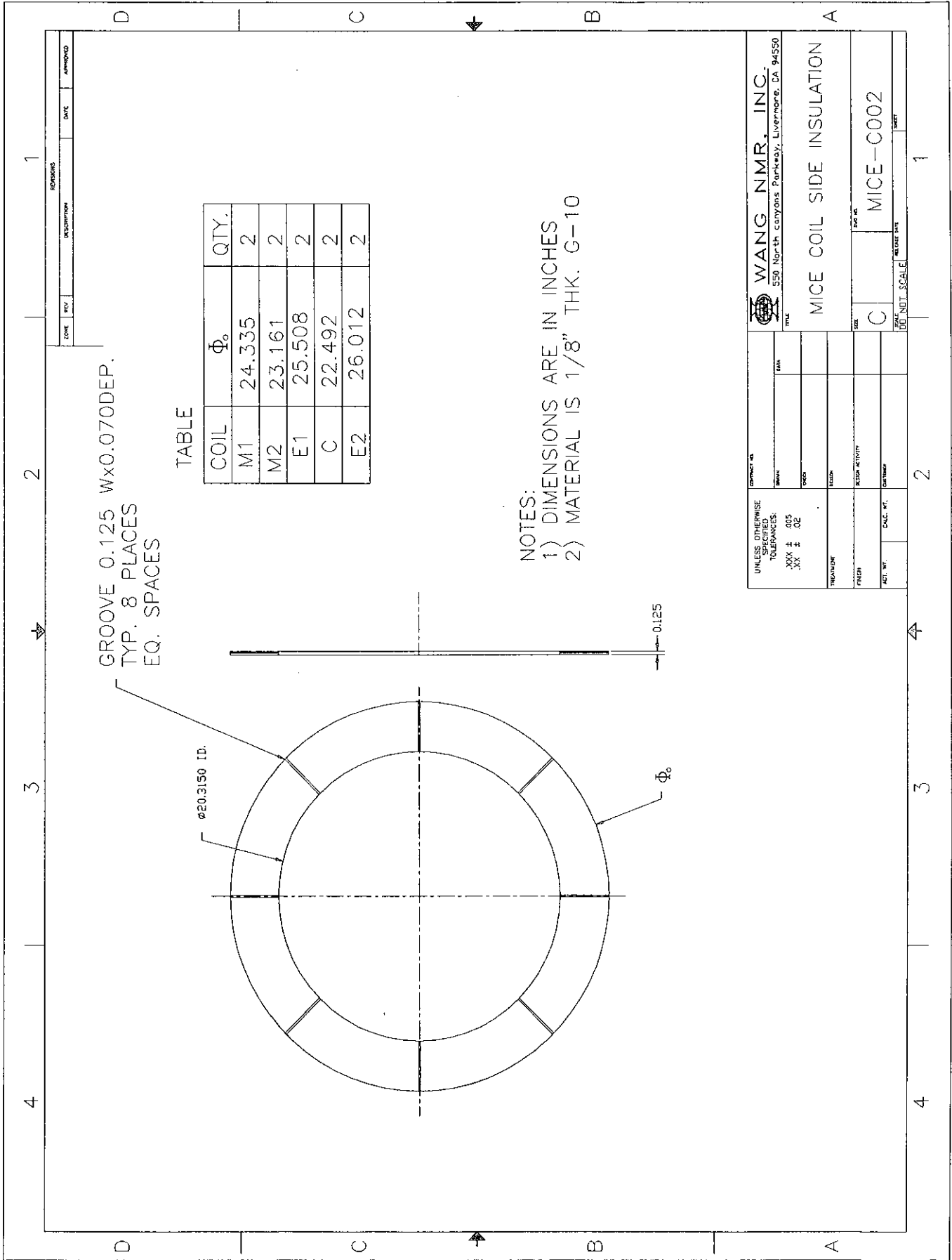
(B) Winding instruction

Appendix II-9-1 and II-9-2 are the winding instruction with number of turns per layer and the dimensional quality control after each layer of coil winding. In addition, a constant current source is used to measure any change of coil resistance due to turn-to-turn short or layer-to-layer short. The short checking system is sensitive enough to check loss of fractional turn. A measurement of winding room temperature and control of room temperature is necessary to assist monitoring of small resistance change. Epoxy curing is also a factor affecting the small change of coil resistance. One must investigate and understand any decrease in coil resistance.

During the winding of each layer, the length of each 100 turns must be measured to make sure that turn density is kept constant and the number of turns per layer is maintained according to the coil design.
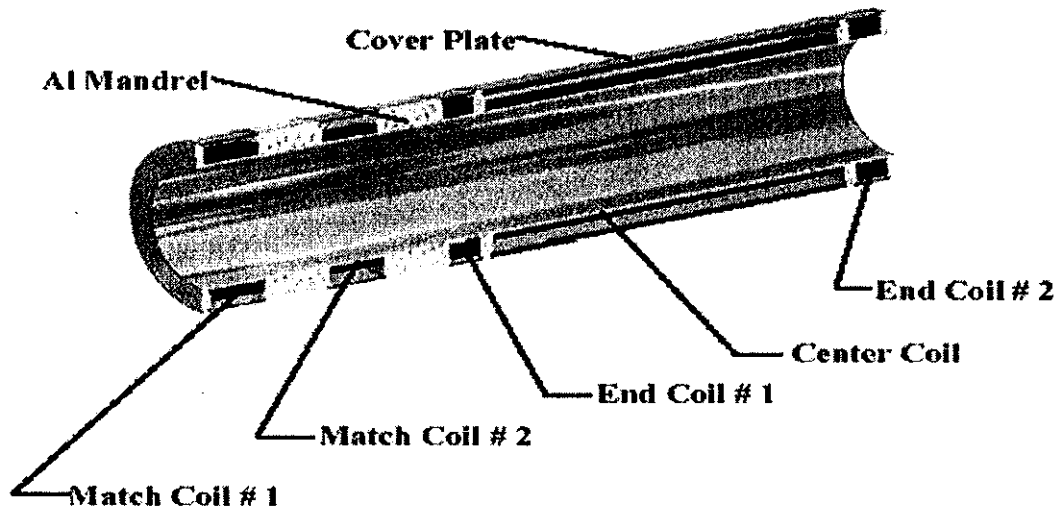
II-10. Coil Banding and Coil Banding Insulation

Outer most coil layer will be insulated with one layer mica (0.003"), two layers kapton (0.002"x2) and one layer of G-10 (0.015"). About 0.25" thick (total), high strength aluminum alloy banding, such as Al 6061T6 or 5052H38 Al will be used to band each coil. The banding will provide some hoop force support and will ensure coil is tightly packed when it is cooldown.

GROOVE 0.125 Wx0.070DEP.
TYP. 8 PLACES
EQ. SPACES

TABLE

COIL	Φ_o	QTY.
M1	24.335	2
M2	23.161	2
E1	25.508	2
C	22.492	2
E2	26.012	2

NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 1/8" THK. G-10

Ø20.3150 I.D.

Φ_o

0.125

TITLE
MICE COIL SIDE INSULATION

DWG NO.
MICE-C002

SIZE
C

SHEET 1

UNLESS OTHERWISE
SPECIFIED
TOLERANCES:
.XXX ± .005
.XX ± .02

CONTRACT NO.
DRAWN
CHECK
DESIGN
DESIGN ACTIVITY
CUSTOMER
TREATMENT
FINISH
ACT. WT.   CALC. WT.
DATA
SCALE   RELEASE DATE

REVISIONS
ZONE   REV   DESCRIPTION   DATE   APPROVED

Figure II-9-1
Winding Instruction Summary
Spool Assignment for TRACKER SOLENOID

Tracker solenoid showing the positions of the five coils

UNIT # 1		Winding Requirement		UNIT # 2	
COIL #	CONDUCTOR SPOOL #	# of Layers	# of Turns per Layer	COIL #	CONDUCTOR SPOOL #
MATCH COIL #1	36680	42	120	MATCH COIL #1	36680
MATCH COIL #2	36679	28	119	MATCH COIL #2	367601-2
END COIL #1	36680	56	66	END COIL #1	36760-1-1
CENTER COIL	36679	20	784	CENTER COIL	36761-1
END COIL #2	36680	62	66	END COIL #2	36760-1-1

SPOOL ASSIGN

II-11. Coil Former Reinforcement Design

Because of significant axial magnetic forces, the coil pack will be exerted with a shear stress. To minimize shear stress and minimize the conductor motion, we shall add ¼" thick reinforce aluminum cylindrical to all coils. These reinforcement cylinders will be welded to connect to its flanges, as shown in Drwg C003.

Since the strength of aluminum weldment is only 10 ksi and ¼" x ¼" weld will support 75 ton.

II-12. Design of Conductor Joints and Voltage Tap

In order to keep I^2R loss for each joint in the order of 4 mW, each conductor joint must have a resistance lower than 10^{-7} Ω. Each unit of tracker magnet shall have about 10 joints. Thus, total I^2R loss will be kept at about 40 mW.

The design of the conductor joint will be lapping joint over at least 24" long. A small R&D program to establish the joint technique and the measuring method for quality control is necessary because it is tricky to measure very low values of resistance.

Voltage tap will be made at each joints. All joints will be carefully insulated, mechanically supported, and epoxy potted in a G-10 supporting groove.

II-13. Design of Superconducting Feedthrough

UHV feedthrough made of hollow copper conductor is custom-made by ISI, as shown in Photo II-13-1. Each feedthrough has 4 hollow copper conductors with an ID of 0.060", OD of 0.125", and a length of 3.5". A 0.051"diameter-24" long superconducting strand rated at 500A are pretinned with soft solder and then, it is soft-soldered to the hollow conductor feedthrough. In order to minimize the I^2R loss, superconducting strands will be lapped joint over 24" to coil terminals.

The superconducting feedthrough must be leak-checked at room temperature as well at liquid helium temperature. It must be thermal cycled several times between 4.2K and 300K to make sure it is vacuum tight to 1 x 10^{-10} torr liter/ sec.

The superconducting feedthru strand at both helium and vacuum side will be soldered with three times more superconductor/ copper composite to avoid burn out and enhance thermal conductivity and stability.
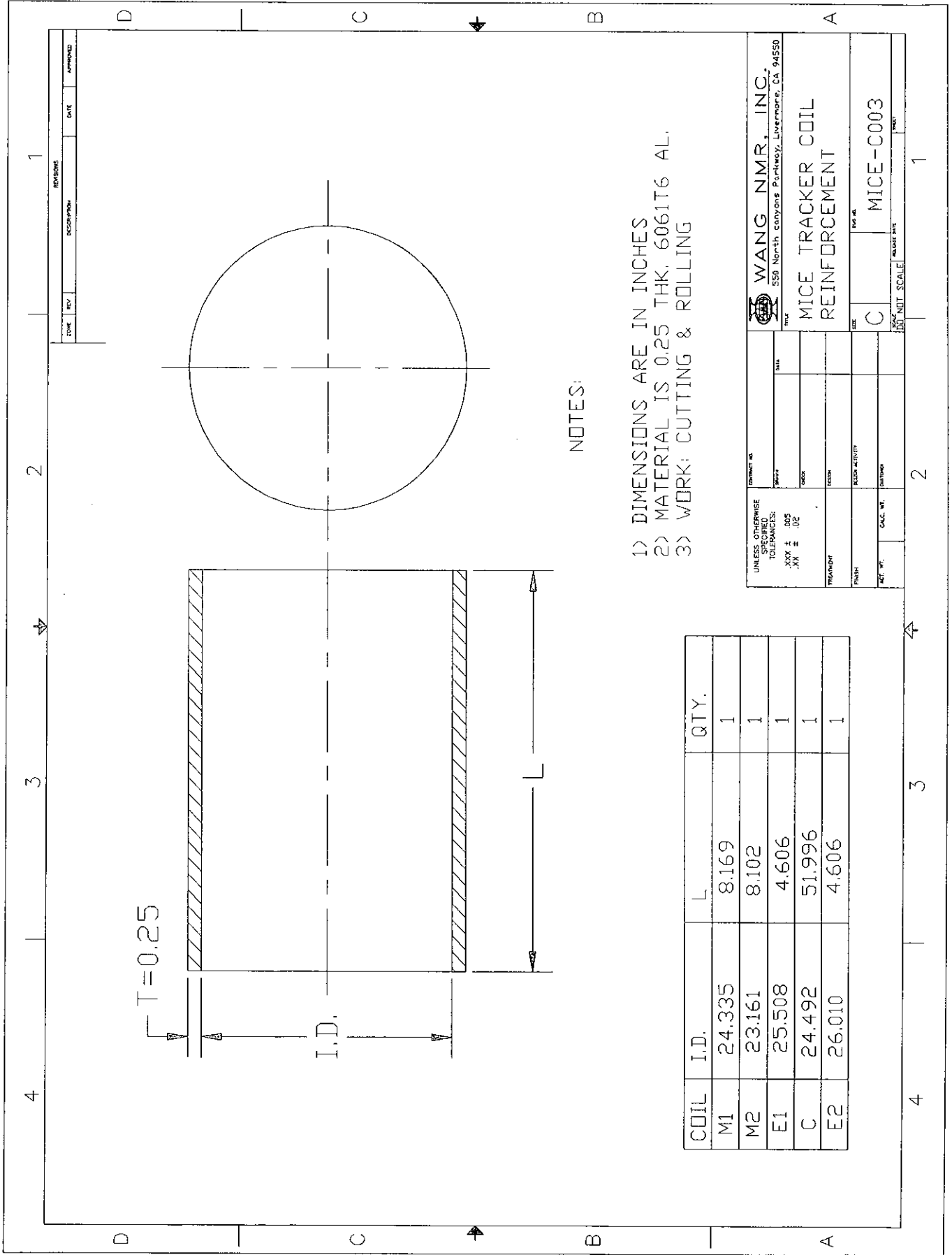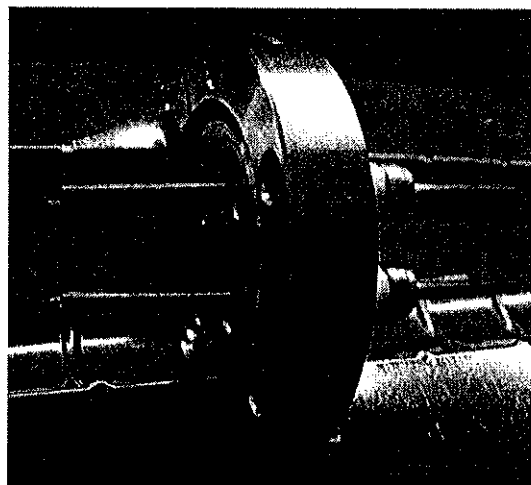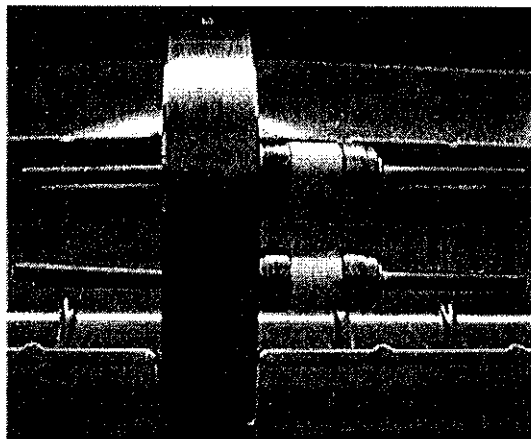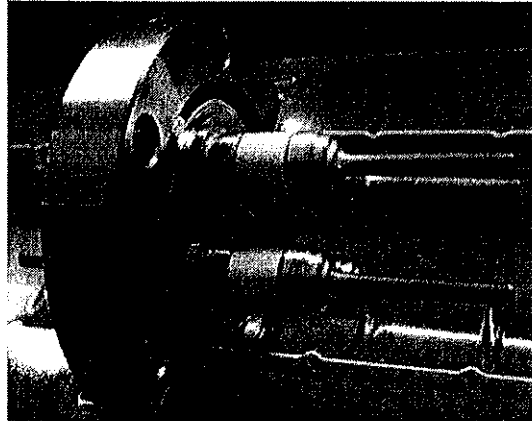
NOTES:

1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 0.25 THK. 6061T6 AL.
3) WORK: CUTTING & ROLLING

T=0.25

I.D.

L

COIL	I.D.	L	QTY.
M1	24.335	8.169	1
M2	23.161	8.102	1
E1	25.508	4.606	1
C	24.492	51.996	1
E2	26.010	4.606	1

TITLE
MICE TRACKER COIL
REINFORCEMENT

SIZE
C

DWG NO.
MICE-C003

UNLESS OTHERWISE
SPECIFIED
TOLERANCES:
XXX ± .005
.XX ± .02

TREATMENT

FINISH

DO NOT SCALE

REVISIONS

ZONE | REV | DESCRIPTION | DATE | APPROVED

Photo II-13-1

II-14. Passive Magnet Protection System

INDUCTANCE AND STORED ENERGY
Table II-14-1 lists the computed self and mutual inductance as well as stored energy of each coil

MAGNET QUENCH PROTECTION SYSTEM

A system of diodes and resistors are used to protect the magnet from damage in the event that one or more coils quench. A schematic of the protection system is illustrated in Figure II-14-1. Quench protection is provided by a low value resistor and a pair of back-to-back diodes connected across each magnet coil. The voltage across each individual magnet is low during the normal charging and discharging of the magnet. At the operating temperature of 4K, the diodes have a threshold voltage on the order of 3 to 5 volts. Therefore, the diodes will not conduct and the resistor is effectively disconnected. If a quench should occur in a particular coil, the coil looses its superconductivity and the voltage across the coil will begin to rise. As the voltage increases, a diode will begin to conduct which will limit the voltage across the coil to a safe value. The diode(s) and resistor provide a current path across the quenching coil to allow the current in the coil to decay. The change of current in the quenching coil will induce voltages in the other coils of the magnet due to their mutual inductance. The circuits across the other coils will protect these coils from excessive voltages. The resistors in series with the diodes are required to limit the current buildup in the coils due to these quench induced voltages.
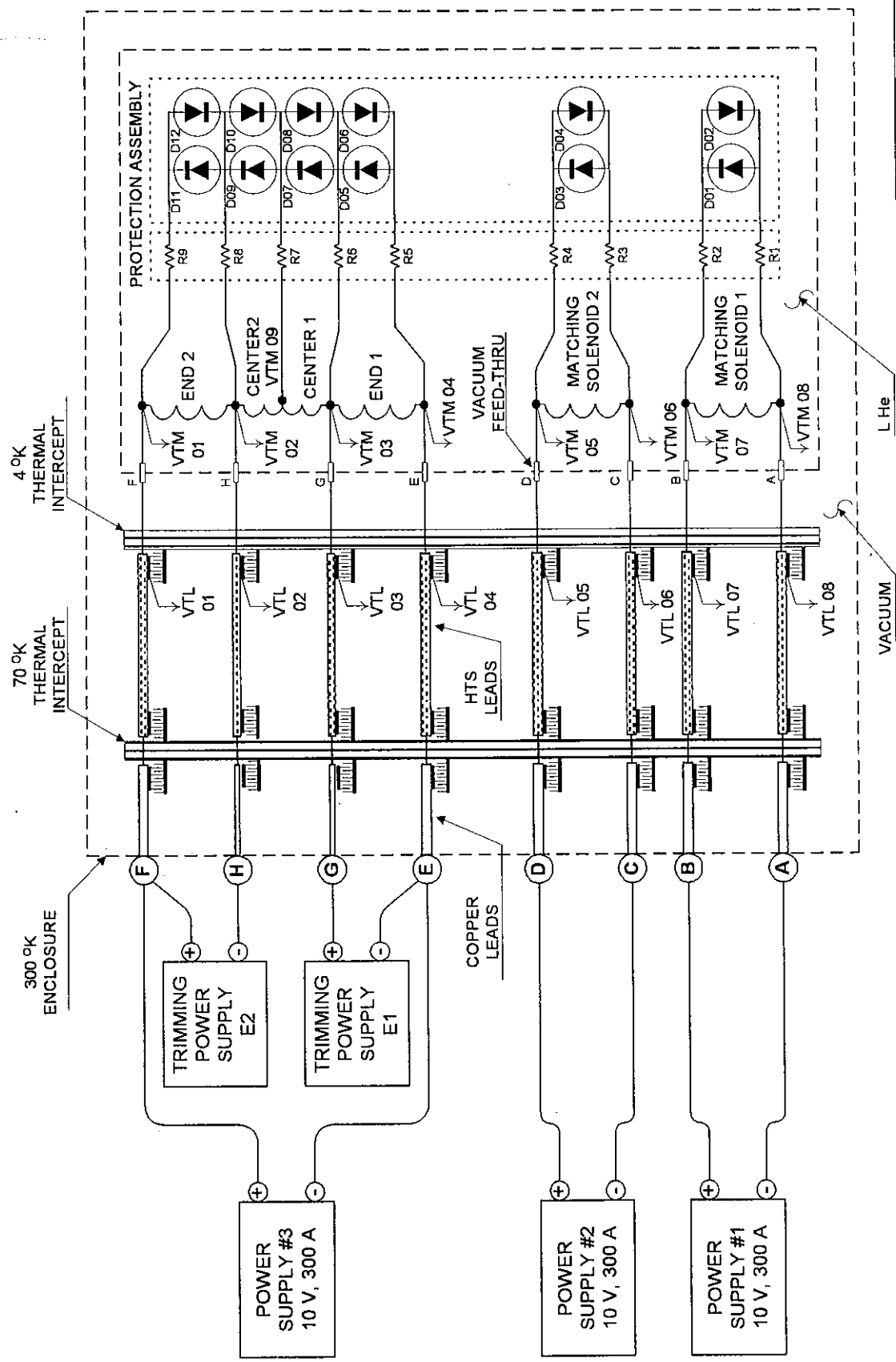
The diodes are an industry type R620 "hockey puck" high current rectifier. This diode has been tested thoroughly at liquid helium temperatures and has been used successfully in many similar protection systems at currents up to 400 amperes. The diodes are mounted in a specially designed assembly which is shown in Figure II-14-2. The diode clamping system utilizes a stack of Bellville washers to maintain the clamping force within specified limits over the full temperature range including the effect of temperature shocks that may be encountered during the magnet cooldown and a magnet quench. The clamp bar and its base plate are shown in Fig PRT4622-A and PRT4621-B.

The resistors R1 to R9 have a value in the range of 0.003 to 0.010 ohms. The actual value will depend upon the coil and mutual inductances. The resistors are fabricated from stainless steel ribbon and are designed with sufficient heat capacity to handle the worst case quench currents safely.

TABLE II-14-1
INDUCTANCE FOR MICE SPECTROMETER MAGNET

DATE : JULY 7, 2006

MICE SPECCTROMETER MAGNET

COIL #	MATCH1	MATCH2	END1	CENTER	END2	TOTAL
SELF INDUCTANCE	15.7160	6.8514	10.5220	43.4850	12.8850	89.4594
MUTUAL INDUCTANCE :						
M1		1.1377	0.3097	0.2823	0.0204	1.7502
M2	1.1377		1.0065	0.5706	0.0235	2.7383
E1	0.3097	1.0065		3.4971	0.0564	4.8697
C	0.2823	0.5706	3.4971		3.8832	8.2333
E2	0.0204	0.0235	0.0564	3.8832		3.9835
TOTAL	17.47	9.59	15.39	51.72	16.87	111.03
OPERATED AMPERE :	214.20	251.80	249.50	265.90	265.20	
STORED ENERGY	0.40	0.30	0.48	1.83	0.59	3.61

TOTAL INDUCTANCE : 111.03 HERNY

TOTAL ENERGY : 3.61 MJ

MAGNET PROTECTION
MICE SPECTROMETER
Wang NMR Inc.

09/05/06 / MICEPROTECTB.VSD

FIGURE II-14-1

PROPRIETARY INFORMATION of Wang N M R INC

WIRING TO MAGNET

G-10 SUPPORT
1.00 x .50

D01   D02
D05   D06
D07   D08

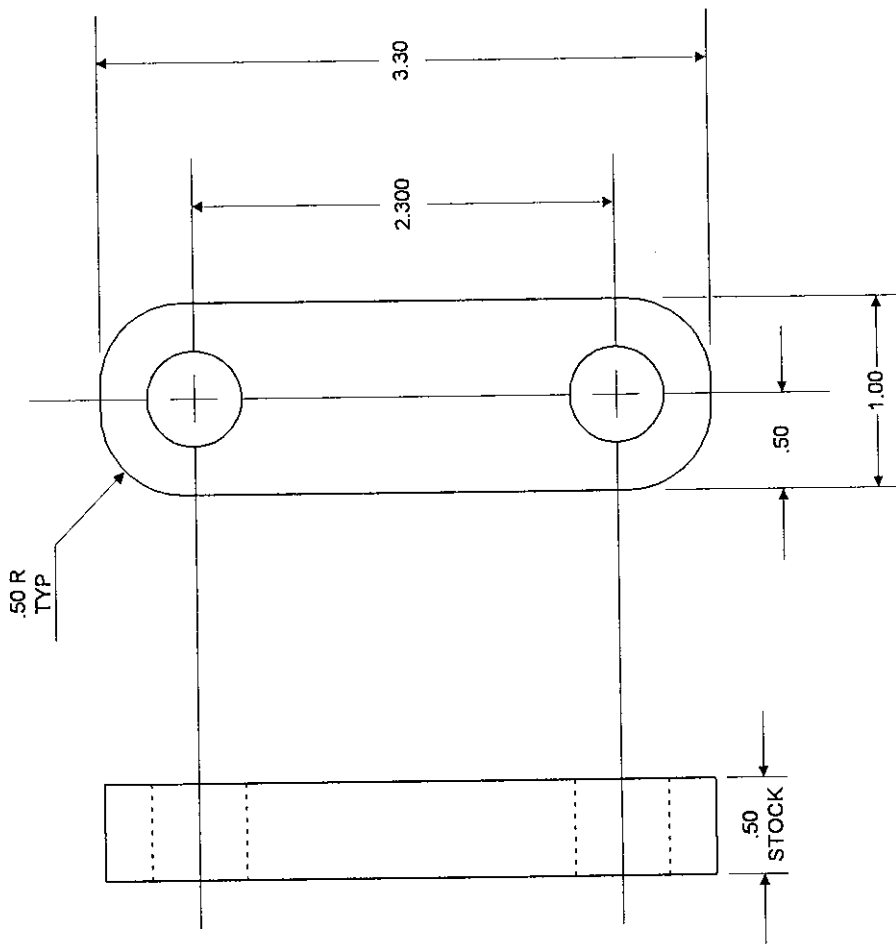D09   D10
D11   D12
D03   D04

7.00
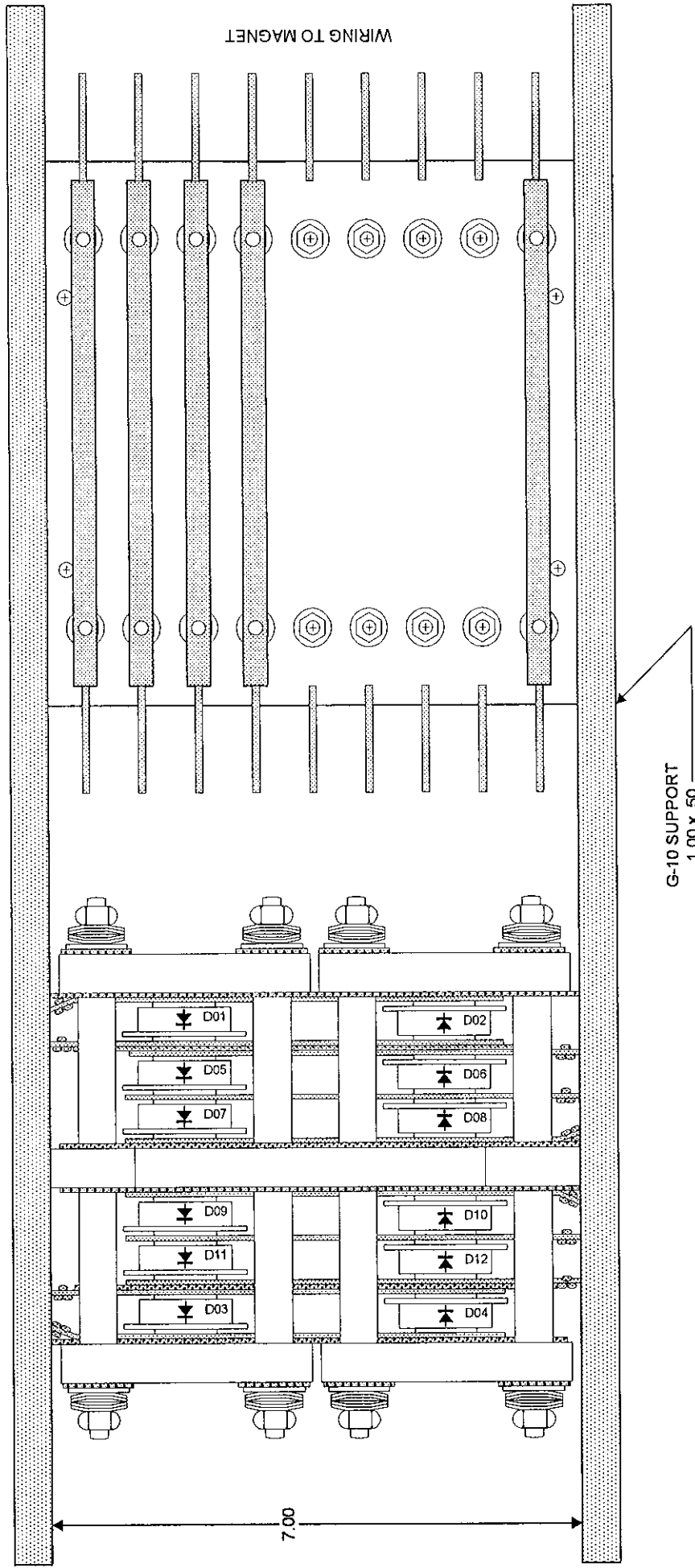
NOTES:
1.
2.
3.
4.

17:16   07/26/06   PROTECT_LAYOUTC.VSD

LAYOUT, PROTECTION ASSEMBLY
MICE MAGNET
Wang NMR Inc.

FIGURE II-14-2

PROPRIETARY INFORMATION of Wang N M R INC

3.30

2.300

1.00

.50

.50 R
TYP

.50
STOCK

NOTES:

1. MATERIAL: ALUMINUM, 1/2 INCH PLATE

2. HOLES: 0.515 (33/64) THROUGH , 2 PLACES

3. QTY REQ = 4

CL

.875
.250

TYP BOTH
ENDS

1.00

07/10/05   PROTECTBASE.VSD

.38
TYP

15°

.850

.650
ref

2.300

.550

.550

2.300

CL
7.00

.500
STOCK

1.70

NOTES:

1. MATERIAL: ALUMINUM, 1/2 INCH PLATE

2. HOLES:
   A. .500 THROUGH   4 PLACES
   B. TAP 1/4-20 .40 DEEP 4 PLACES

3. QTY REQ = 1

PROTECTION DIODE
MOUNTING BASE PLATE
Wang NMR Inc

PRT 4621 -B

PROPRIETARY INFORMATION
of Wang N M R INC

II-15. 3-D Magnet Quench Analyses for MICE Tracker Magnet

We perform quench analyses based on assumption that aluminum bore tube does not exist. Employing each coil self-inductance, dividing the center coil into two coils, and assuming the initial protection resistor in series with each protection diode is 0.01 Ω, then the 3D XYZ coil volume, is measured as follows:

X = coil thickness
Y = coil circumference
Z = coil axial length

Assume the turn-to-turn initial velocity of propagation is 2×10^{-3} Vo, and layer-to-layer initial velocity of propagation is 2×10^{-3} Vo, where Vo is the initial velocity of propagation and is computed to be about 24 m/ sec. Then, 3D quench analyses is shown in Appendix II-15-1.

Table II-15-1 summarizes results of quench computation for the maximum coil temperature, the maximum internal voltage, the maximum coil resistance R and the quench time.

All coils, when quenches, will have induced unbalanced voltage of order of 1000V. It is clear that why coil must be meggered to 5 kV (in air) in order to sustain the maximum unbalanced voltage (in helium gas) for each of the tracker coils. The detail 3D quench analyses of each coil is shown in Appendix II-15-1 to II-15-5.

In reality, aluminum cold bore tube is a very low resistance short turn. This will slow down the di/ dt and help dissipate the energy. Therefore, actual interval voltage and unbalance voltage will be significantly small.

TABLE II-15-1 3D Quench Analyses

Coil	M1	M2	E1	C (half)	E2
Quench time	2.4 sec	3.6 sec	4.4 sec	3 sec	4.2 sec
Maximum R	9.6 Ω	6.0 Ω	7.1 Ω	12.0 Ω	8.9 Ω
Maximum internal V	1143 V	454 V	857 V	1637 V	1094 V
Maximum temperature	135K	83K	131K	86K	155K

II-16. Fringing Field Calculation and Evaluation of Effect on HiTc Lead

Effect of magnetic field and temperature on HiTc lead is shown in Fig II-16-1. Therefore, HiTc lead service tower is designed so that hot end of these leads are position at $R \geq 70$ cm and $Z \geq 180$ cm where $Z = 0$ is defined at the further end flange of M1 coil. Fringing field calculation is tabulated in TableII-16-1. As shown in TableII-16-1, the maximum $Bz \fallingdotseq 650$ to 700 Gauss and the maximum $B_R = 120$ to 240 gauss. When we orient the HiTc lead so that HiTc conductor broad face is parallel to B_R and Bz then $B_{||} \leq 700$ gauss and thus at a hot end of 64K temperature, high Tc lead, reduction of current scaling factor is about 5 to 10 %. Therefore 500A lead become 450A and 100A lead become 90A.

Table II-16-1

LBL MICE SOLENOID TRACKER SUPERCONDUCTING SYSTEM
FRINGE FIELD COMPOMENT ON HI-TC LEAD AREA

UNIT: G

Z POSITION (cm)	180	190	200
R= 45 CM (HZ)	-651	-708	-801
R= 45 CM (HR)	55	42	11
R= 45 CM (HT)	654	710	802
R= 55 CM(HZ)	-647	-708	-809
R= 55 CM (HR)	88	105	126
R= 55 CM (HT)	654	717	819
R= 60 CM(HZ)	-637	-695	-789
R= 60 CM (HR)	102	132	175
R= 60 CM (HT)	646	708	808
R= 70 CM(HZ)	-602	-648	-717
R= 70 CM (HR)	125	174	242
R= 70 CM (HT)	615	671	757

Fig II-16-1 CURRENT SCALING FACTORS FOR MAGNETIC FIELD AND TEMPERATURE
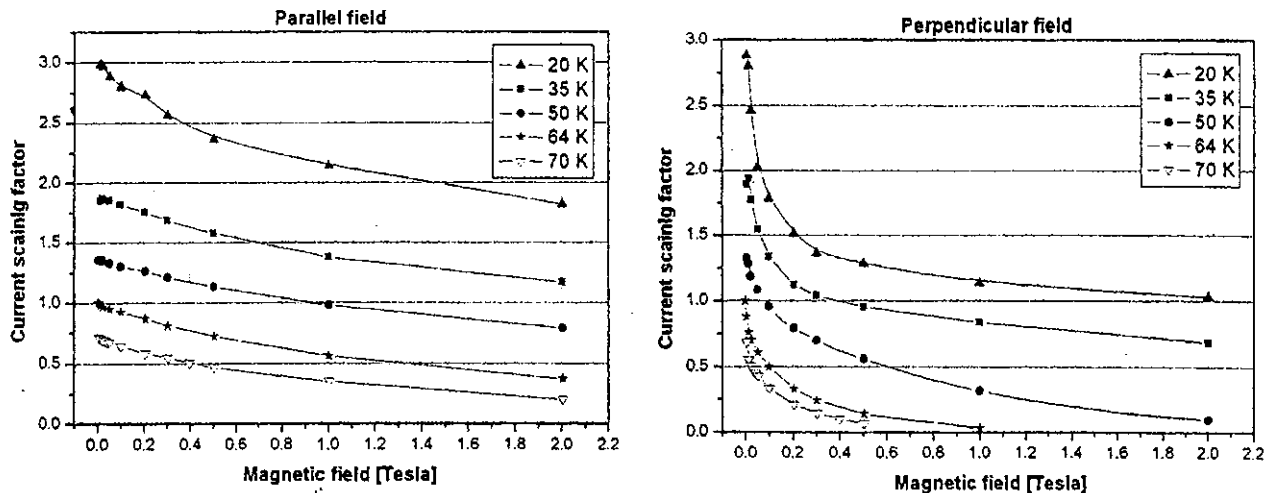
II-17. Fringing Field Calculation and Effect on Cryocooler Cold Head

Our three pulse tube cryocoolers cold head are positioned as shown in Table II-17-1. It is clear that fringing field at each 300K, 60K and 4.2K stage is less than 1600 gausses. If there is any problem, the valve portion of 300K cold head could be operated at a position at a lower field region

Table II-17-1

FRINGE FIELD CALCULATION

LBL MICE TRACKER SOLENOID SUPERCONDUCTING SYSTEM (FRINGE FIELD COMPOMENT IN COLDHEAD)

HZ : AXIAL COMPONENT OF MAGNETIC INDUCTION

HR: RADIAL COMPONENT OF MAGNETIC INDUCTION;

HT: TOTAL MAGNETIC INDUCTION

CRYCOOLER REGION

UNIT: G

Z POSITION (cm)	80	90	100	110	120	130	140	150	160	170
R= 45 CM (HZ)	689	-1559	-2837	-1647	-924	-694	-617	-594	-596	-616
R= 45 CM (HR)	-2699	-3428	-1014	384	348	206	125	86	68	61
R= 45 CM (HT)	2786	3769	3014	1691	987	724	630	600	600	619
R= 55 CM(HZ)	-257	-922	-1356	-1203	-914	-732	-643	-605	-597	-612
R= 55 CM (HR)	-1500	-1536	-889	-259	-11	45	53	56	63	74
R= 55 CM (HT)	1522	1792	1621	1231	915	734	645	608	601	617
R= 60 CM(HZ)	-379	-776	-1051	-1013	-848	-713	-636	-600	-591	-603
R= 60 CM (HR)	-1185	-1154	-764	-339	-106	-14	22	42	59	79
R= 60 CM (HT)	1244	1390	1299	1068	854	713	636	601	594	609
R= 70 CM (HZ)	-433	-602	-729	-753	-706	-643	-597	-572	-565	-575
R= 70 CM (HR)	-810	-748	-567	-353	-188	-85	-24	18	53	87
R= 70 CM (HT)	919	960	924	832	730	650	598	572	567	582
R= 80 CM (HZ)	-412	-498	-568	-596	-589	-566	-544	-529	-526	-535
R= 80 CM (HR)	-603	-544	-438	-313	-199	-111	-46	5	48	91
R= 80 CM (HT)	730	738	717	673	622	577	546	530	529	542
R= 90 CM (HZ)	-373	-426	-469	-494	-500	-495	-487	-482	-481	-488
R= 90 CM (HR)	-474	-423	-350	-266	-184	-123	-53	-1	46	92
R= 90 CM (HT)	603	600	585	561	533	508	490	482	484	497
R= 100 CM (HZ)	-335	-370	-401	-421	-432	-435	-434	-434	-435	-440
R= 100 CM (HR)	-385	-342	-287	-225	-163	-104	-51	-2	44	91
R= 100 CM (HT)	511	504	493	478	461	447	437	434	437	449

4.2 K

6 4 K

3 0 0 K

Cold head   First   Second   Third
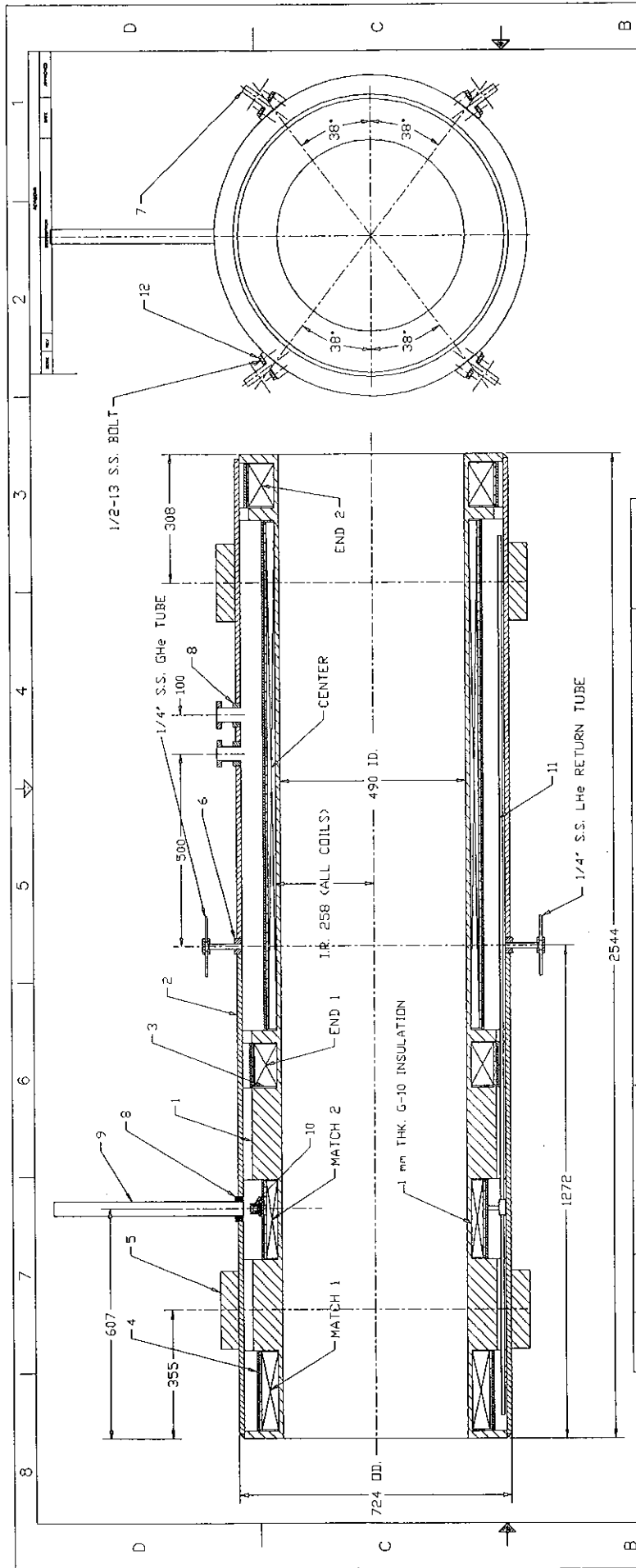
Appendix II-1-1

Engineering Design Drawing For Coil Structure
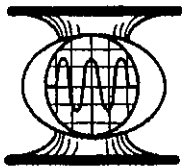
Wang NMR Inc.

• 550 North Canyons Parkway • Livermore, CA 94551

NOTES:
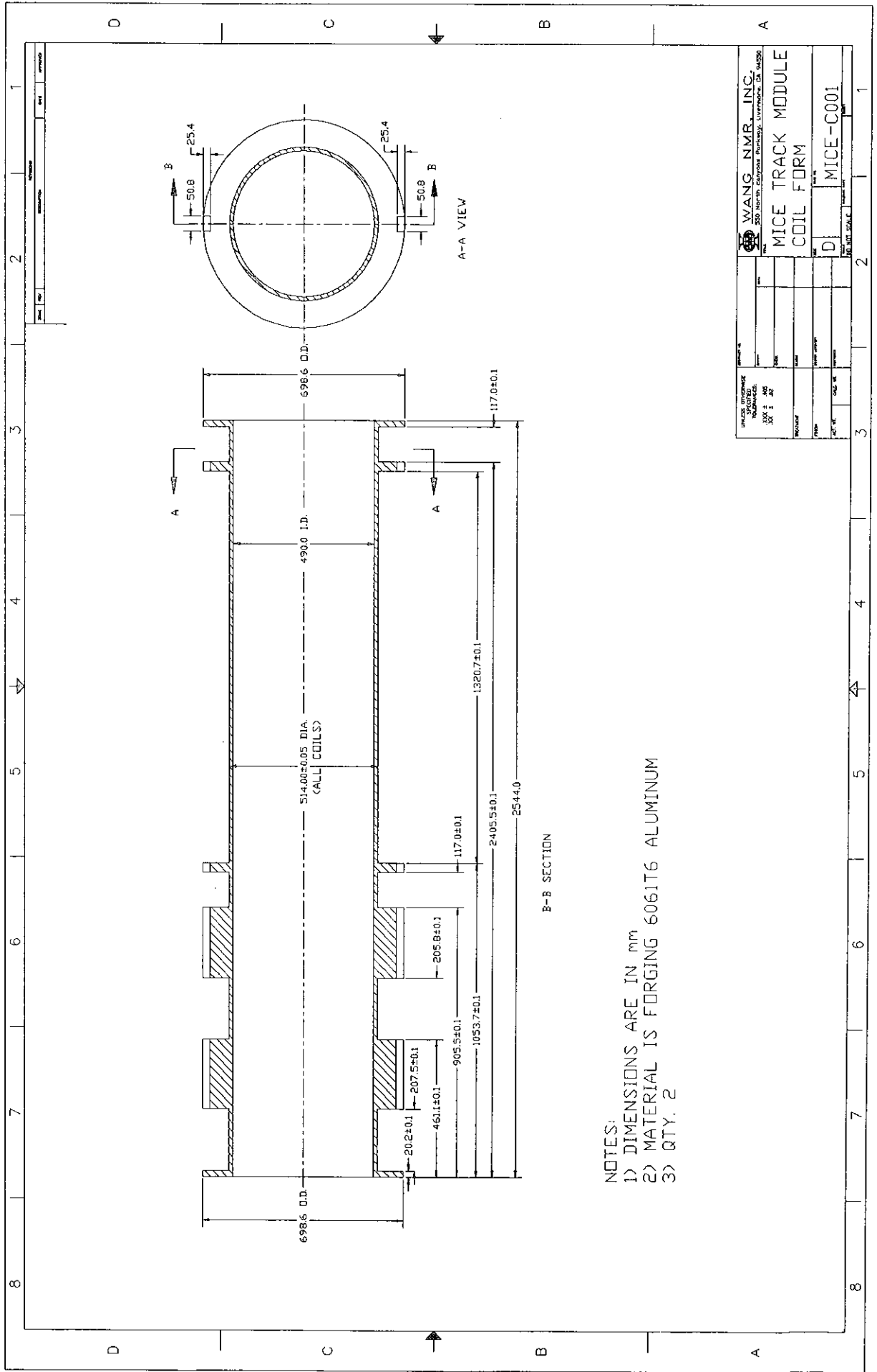1) DIMENSIONS ARE IN mm
2) REQD. VACUUM TIGHT (LEAK CHECK)

WANG NMR, INC.
550 North Canyons Parkway, Livermore, CA 94550

MICE TRACKER MODULE
COIL STRUCTURE

D   MICE-C0000

QTY.	ITEM	DWG. No.	DESCRIPTION	NOTE
32	12	MICE-C012	WASHER	304 S.S.
1	11	MICE-C011	PRECOOL LINE	304 S.S.
1	10	MICE-C010	PRECOOL NOZZLE	304 S.S.
1	9	MICE-C009	NECK TUBE	304 S.S.
2	8	MICE-C008	BI-METAL COUPLING	AL- S.S.
8	7	MICE-C007	COLD MASS SUPPORT BLACKET	316 S.S.
2	6	MICE-C006	BI-METAL COUPLING	AL- S.S.
2	5	MICE-C005	SUSPESION RING	6061T6
5	4	MICE-C004	REINFORCEMENT	6061T6
10	3	MICE-C003	SIDE INSULATION	G-10
2	2	MICE-C002	LHe VESSEL	6061T6
1	1	MICE-C001	COIL FORM	6061T6

1/2-13 S.S. BOLT

1/4" S.S. GHe TUBE

1/4" S.S. LHe RETURN TUBE

1 mm THK. G-10 INSULATION

CENTER

END 1
END 2

MATCH 1
MATCH 2

490 ID.
I.R. 258 (ALL COILS)
308
100
500
2544
1272
607
355
724 O.D.

38°

A-A VIEW

25.4
50.8
50.8
25.4

B

B

698.6 O.D.

490.0 I.D.

514.00±0.05 DIA.
(ALL COILS)

698.6 O.D.

117±0.1

1320.7±0.1

117±0.1

2405.5±0.1

2544.0

205.8±0.1

905.5±0.1

1053.7±0.1

207.5±0.1

461.1±0.1

20.2±0.1

A

A

B-B SECTION

NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS FORGING 6061T6 ALUMINUM
3) QTY. 2

DETAIL "A"

10×45° TRAMFER
BOTH EDGES

12.7 THICK.

I.R.349.3

180°

2.7

Ø63.5 BORING THRU.
3 PLACES

25.4 DR. THRU.

594

681

500.0

2518.6

100.0

45°

2.7

DETAIL "A"

NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 1/2" THICK 6061T6 ALUMINUM PLATE
3) WORK: CUTTING MATERIAL, ROLLING & TRAMFER EDGES
4) QTY. 1

WANG NMR, INC.
550 North Canyon Parkway, Livermore, CA 94550

COIL FORM
COVER

D   MICE-C002

DO NOT SCALE

UNLESS OTHERWISE
SPECIFIED
TOLERANCES
.XX ± .025
.X ± .02

DETAIL "A"

10×45° TRAMFER BOTH EDGES

12.7 THICK.

I.R.349.3

2.7

180°

45°

2.7

DETAIL "A"

25.4 DR. THRU.

2518.6

1260

NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 1/2" THICK 6061T6 ALUMINUM PLATE
3) WORK: CUTTING MATERIAL, ROLLING & TRAMFER EDGES
4) QATY. 1

TABLE

COIL	Φ_o	QTY.
M1	24.335	2
M2	23.161	2
E1	25.508	2
C	22.492	2
E2	26.012	2

GROOVE 0.125 Wx0.070DEP.
TYP. 8 PLACES
EQ. SPACES

NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 1/8" THK. G-10

Ø20.3150 ID.

0.125

Φ_o

TITLE
MICE COIL SIDE INSULATION

SIZE C

MICE-C003

DO NOT SCALE

UNLESS OTHERWISE
SPECIFIED
TOLERANCES:
.XXX ± .005
.XX ± .02

CONTRACT NO.
DRAWN
CHECK
DESIGN
DESIGN ACTIVITY
ENGINEER

TREATMENT
FINISH
ACT. WT. | CALC. WT.

SCALE | RELEASE DATE
SHEET 1

T=0.25

I.D.

L

NOTES:

1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 0.25 THK. 6061T6 AL.
3) WORK: CUTTING & ROLLING

COIL	I.D.	L	QTY.
M1	24.335	8.169	1
M2	23.161	8.102	1
E1	25.508	4.606	1
C	22.492	51.996	1
E2	26.010	4.606	1

TITLE: MICE TRACKER COIL REINFORCEMENT

SIZE: C

DWG. NO.: MICE-C004

SHEET 1

UNLESS OTHERWISE SPECIFIED TOLERANCES:
XXX ± .005
XX ± .02

DO NOT SCALE

REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED

V

728 I.D.

828 O.D.

200

38° 38°

38° 38°

A

A

A

NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 6061T6
3) QTY. 2

1/2-13 TAP THRU.
4 PLACES EACH FACE
TOTAL 16 PLACES

120

52

200

84

WANG NMR, INC.
550 North canyons Parkway, Livermore, CA 94550

TITLE
SUSPENSION RING

SIZE
C

DWG NO.
MICE-C005

DO NOT SCALE

UNLESS OTHERWISE
SPECIFIED
TOLERANCES:
.XXX ± .005
.XX ± .02

3/8" OD. 0.035" WALL
304 S.S. TUBE

ALUMINUM

S.S.-Al BI-METAL

25.4 OD.

72.0

22 IN STOCK

S.S.

12.0 DIA. 9.53 DIA.

1.0

NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS S.S.-Al BI-METAL & 3/8" OD.
   0.035" WALL 304 S.S. TUBE
3) QTY. 2

A–A SECTION

75
37
17°
17°
30
20
36
17°
32
20
9
44.45 −0.00 −0.02 DIA.

13.0 DR. THRU.
4 PLACES AS SHOWN AS DWG.

120
150

A
A

NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 316 S.S.
3) QTY. 8

TITLE
COLD MASS SUPPORT
BRACKET

DWG. NO.
MICE-C007

SIZE C

DO NOT SCALE

REVISIONS
ZONE | REV | DESCRIPTION | DATE | APPROVED

UNLESS OTHERWISE
SPECIFIED
TOLERANCES:
.XXX ± .005
.XX ± .02

CONTRACT NO.
DRAWN
CHECK
DESIGN
DESIGN ACTIVITY
CUSTOMER
TREATMENT
FINISH
ACT. WT.
CALC. WT.

D   C   B   A
1   2   3   4

21.6 IN STOCK

38.1 ID. 63.5 OD.

FIT 15" TUBE

REF.

69.3 OD.

MDC 2-3/4" HALF NIPPLE

NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS S.S.-AL BI-METAL
   & MDC 2-3/4" HALF NIPPLE
3) QTY. 2

REVISIONS
ZONE REV DESCRIPTION DATE APPROVED

D

C

B

A

36.82 DIA.

36.82 DIA.

36.32 ID.

38.1 DB.

12.70

87.30

12.70

374.60

500.00

12.70

NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 1.5" OD. 0.035" WALL 304 S.S.TUBE
3) QTY. 1

NECK TUBE

D | MICE-C009

UNLESS OTHERWISE
SPECIFIED
TOLERANCES
.XX ± .005
.XXX ± .002

41.40 O.D.

7.75

3.00

5.00

30.00

11.40 DIA.

90°

25.40 DIA.

4.0 DR. THRU.
3 PLACES 90°
APART
ON B.C.33.40

⌀33.40

9.54 DR. THRU.
FOR WELDING
3/8" PRECOOL
LINE

NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 304 S.S.
3) QTY. 1

PRECOOL NOZZLE
(MICE-C010)

R316

3/8" OD. 0.035 WALL 304 S.S. TUBE

PRECOOL NOZZLE
(MICE-C010)

1719

DRILL 1/4" HOLES AT BOTTOM
300 APART

3/8" T

513

NOTES:
1) DIMENSIONS ARE IN mm

Ø22.00

Ø13.00

A-A

17°

1.00

NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 304 S.S.
3) QTY, 32

REVISIONS

Appendix II-6-1

Finite Element Stress Analyses of

Coil and Reinforce Rings
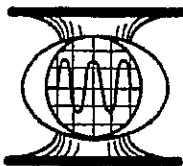
Wang NMR Inc.

• 550 North Canyons Parkway • Livermore, CA 94551

END 2   Compressive Stress

IMAGES-3D
VER. 2.0

= 2.089E+2
= 1.920E+2
= 1.750E+2
= 1.581E+2
= 1.412E+2
= 1.243E+2
= 1.073E+2
= 9.045E+1
= 7.353E+1
= 5.660E+1
= 3.967E+1

Unit
Kg/cm²
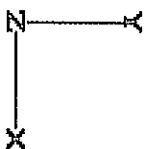
Load Case
1

Stress Contour Plot
G1 St: S22
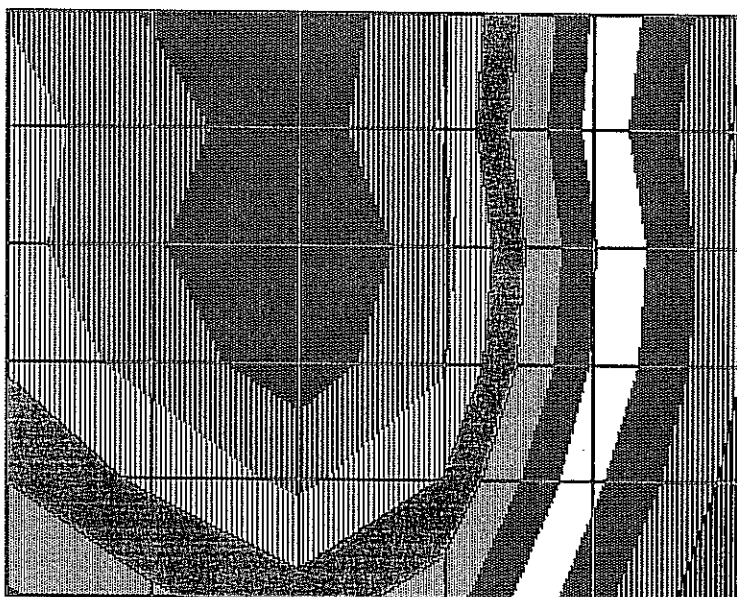
8/10/6
6:42:52

END 2 hoop stress

IMAGES-3D
VER. 2.0

unite kg/in²

6.377E+2
6.602E+2
6.827E+2
7.052E+2
7.277E+2
7.502E+2
7.727E+2
7.952E+2
8.177E+2
8.402E+2
8.627E+2
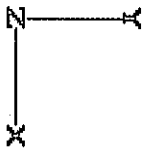
Load Case
1

Stress Contour Plot
G1 St: S33
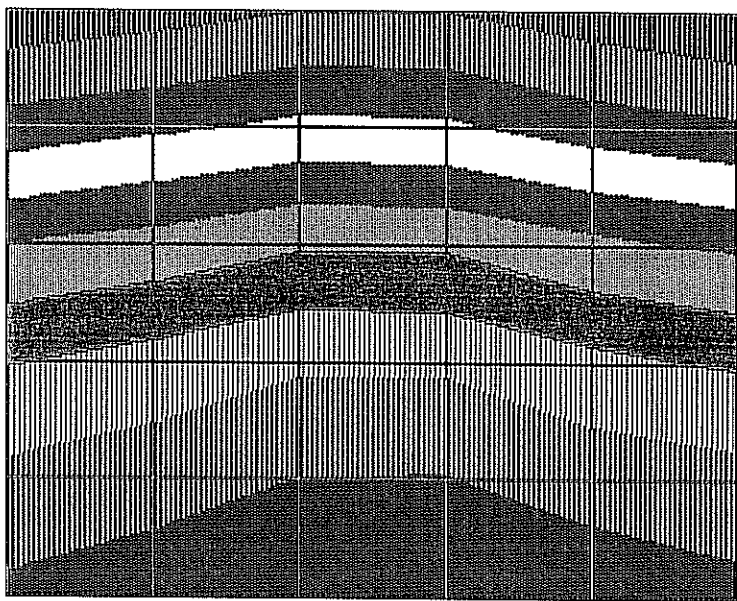
8/18/ 6
6:42:24

CENTER

IMAGES-3D
VER. 2.0

1.466E+0
5.276E+0
9.086E+0
1.289E+1
1.670E+1
2.051E+1
2.432E+1
2.813E+1
3.194E+1
3.575E+1
3.956E+1

Z
Y
X

unite
Kg/in^2
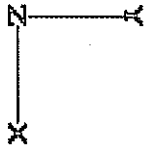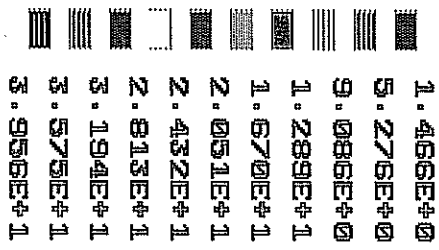
Load Case
1

Stress Contour Plot
G1 St: S22

8/10/ 6
5:26:56

CENTEK

IMAGES-3D
VER. 2.0

7.173E+2
7.274E+2
7.375E+2
7.475E+2
7.576E+2
7.676E+2
7.777E+2
7.878E+2
7.978E+2
8.079E+2
8.180E+2

units
Kg/cm²

Z
Y
X
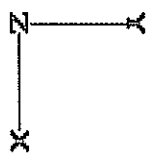
Load Case
1

Stress Contour Plot
G1 St: S33

8/10/6
5:26:17

END 1

IMAGES-3D
VER. 2.0

= 1.561E+2
= 1.435E+2
= 1.308E+2
= 1.182E+2
= 1.056E+2
= 9.299E+1
= 8.035E+1
= 6.772E+1
= 5.508E+1
= 4.245E+1
= 2.982E+1

units kg/cm²
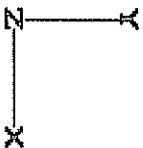
Load Case
1

Stress Contour Plot
G1 St: S22
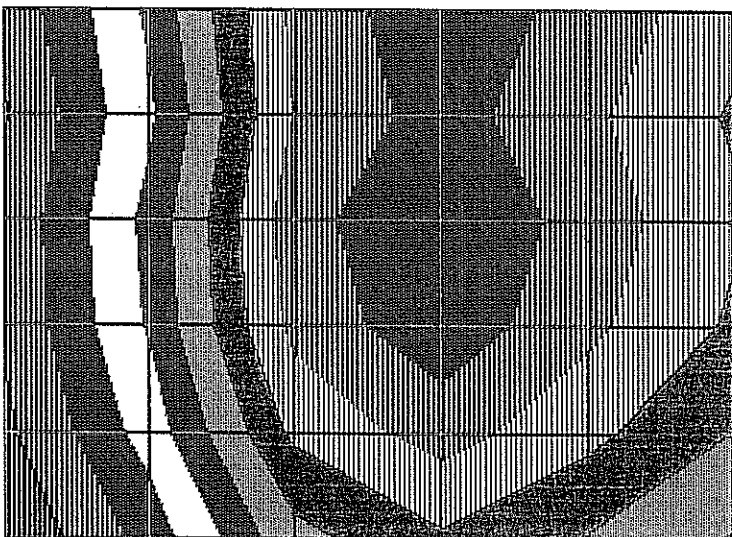
8/ 9/ 6
12:26:27

END 1

IMAGES-3D
VER. 2.0

6.366E+2
6.564E+2
6.762E+2
6.960E+2
7.158E+2
7.356E+2
7.554E+2
7.753E+2
7.951E+2
8.149E+2
8.347E+2

Z
Y
X

write kg/in^2
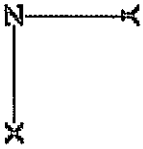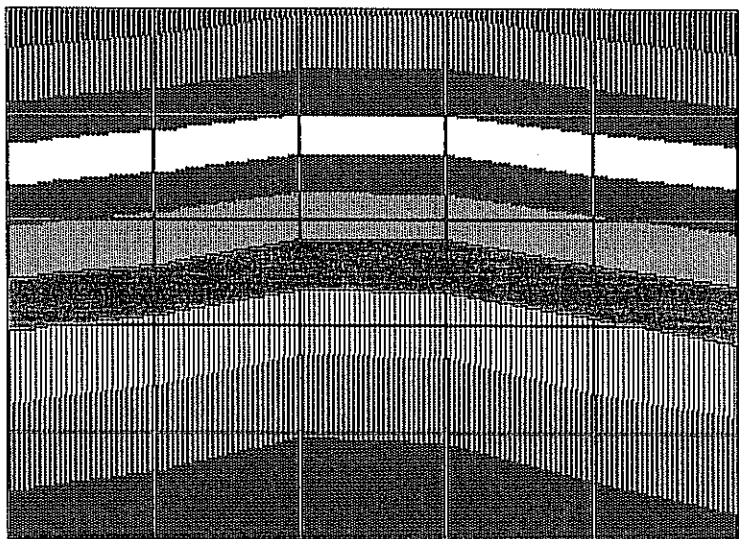
Load Case
1

Stress Contour Plot
G1 St: S33

8/ 9/ 6
12:25:59

MATCH 2

IMAGES-3D
VER. 2.0

= 1.247E+2
= 1.157E+2
= 1.066E+2
= 9.764E+1
= 8.859E+1
= 7.955E+1
= 7.050E+1
= 6.146E+1
= 5.241E+1
= 4.336E+1
= 3.432E+1
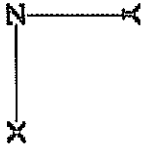
Z

Y

X

unite kg/in²

Load Case
1

Stress Contour Plot
61 St: S22

8/ 9/ 6
11:39:21
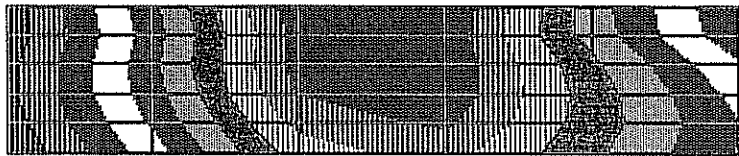
IMAGES-3D
VER. 2.0

5.330E+2
5.440E+2
5.551E+2
5.661E+2
5.771E+2
5.882E+2
5.992E+2
6.102E+2
6.213E+2
6.323E+2
6.433E+2

unite kg/cm²

Z Y X
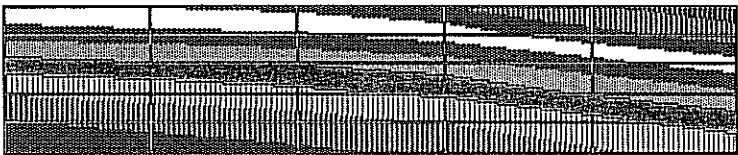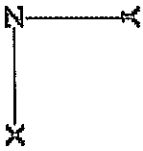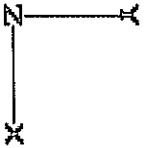
Load Case
1

Stress Contour Plot
G1 St: S33

8/ 9/ 6
11:38:53

MATCH 1

unite rg/cm²

IMAGES-3D
VER. 2.0

3.843E+2
3.997E+2
4.152E+2
4.306E+2
4.461E+2
4.615E+2
4.770E+2
4.924E+2
5.079E+2
5.233E+2
5.388E+2

Load Case
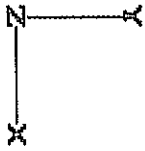1

Stress Contour Plot
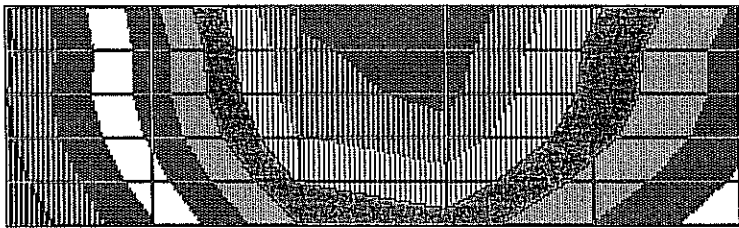GI St: S33

8/ 9/ 6
10:36:20

MATCH 1

IMAGES-3D
VER. 2.0

= 1.825E+2
= 1.685E+2
= 1.546E+2
= 1.406E+2
= 1.266E+2
= 1.127E+2
= 9.878E+1
= 8.483E+1
= 7.087E+1
= 5.692E+1
= 4.296E+1

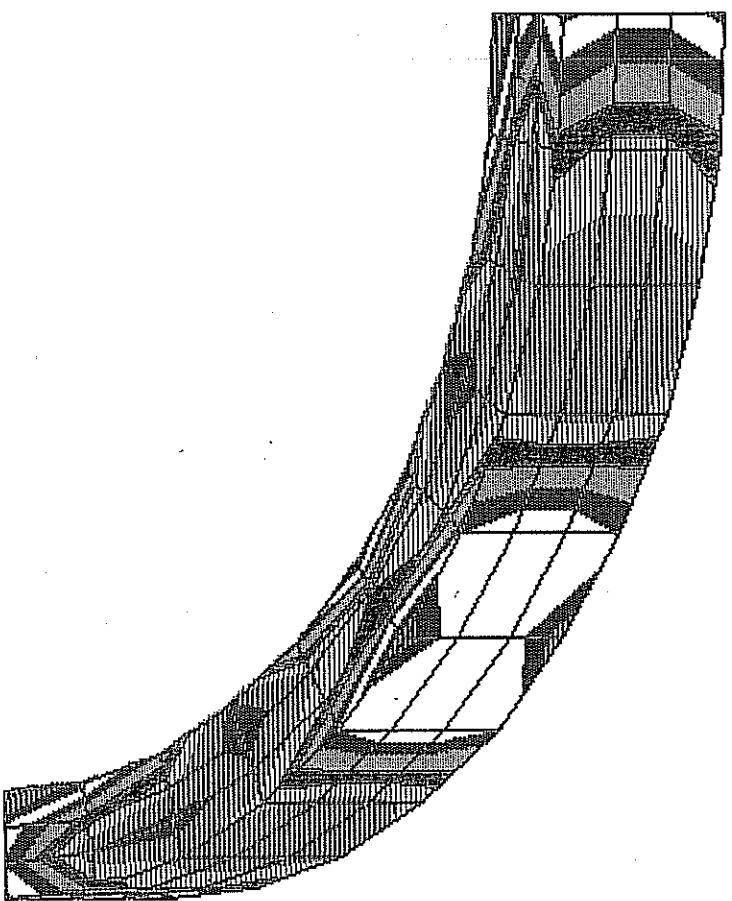Z Y X

unite Kg/cm²

Load Case
1

Stress Contour Plot
G1 St: S22
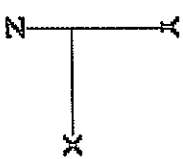
8/ 9/ 6
10:37:25

4.2 K Reinforcement Stress.

unit kg/cm².

IMAGES-3D
VER. 2.0

4.505E+1
1.366E+2
2.281E+2
3.197E+2
4.113E+2
5.028E+2
5.944E+2
6.860E+2
7.775E+2
8.691E+2
9.606E+2

Z
Y
X

Load Case
1

Stress Contour Plot
Von Mises

8/11/6
6:49:33